

IOWA STATE UNIVERSITY

Digital Repository

Graduate Theses and Dissertations

Iowa State University Capstones, Theses and
Dissertations

2011

Examining the Relationship Between Sleep and Obesity Using Subjective and Objective Methods

Shiny Parsai

Iowa State University

Follow this and additional works at: <https://lib.dr.iastate.edu/etd>

 Part of the [Nutrition Commons](#)

Recommended Citation

Parsai, Shiny, "Examining the Relationship Between Sleep and Obesity Using Subjective and Objective Methods" (2011). *Graduate Theses and Dissertations*. 10209.

<https://lib.dr.iastate.edu/etd/10209>

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

Examining the relationship between sleep and obesity using subjective and objective
methods

by

Shiny Parsai

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Nutritional Sciences

Program of Study Committee:

Lorraine Lanningham-Foster, Major Professor
Christina Campbell
Gregory Welk

Iowa State University

Ames, Iowa

2011

Copyright © Shiny Parsai, 2011. All rights reserved.

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION	1
CHAPTER II: REVIEW OF LITERATURE.....	3
INTRODUCTION.....	3
OVERVIEW OF OBESITY	3
<i>Prevalence of Obesity.....</i>	3
<i>Causes and Consequences of Obesity</i>	4
OVERVIEW OF SLEEP	5
<i>Sleep in General Population.....</i>	5
<i>Sleep in Women</i>	6
<i>Causes and Consequences of Sleep Loss.....</i>	7
<i>Public Health Recommendations.....</i>	8
OVERVIEW OF SLEEP AND OBESITY.....	9
<i>Studies in Children</i>	9
<i>Studies in Adults</i>	11
<i>Possible Mechanisms of Sleep and Obesity.....</i>	13
ASSESSMENT OF BODY FAT.....	16
<i>Hydrostatic weighing.....</i>	16
<i>BOD POD®.....</i>	17
<i>Body Mass Index (BMI).....</i>	21
ASSESSMENT OF PHYSICAL ACTIVITY	23
<i>Doubly Labeled Water.....</i>	25
<i>Accelerometers</i>	26
Modular Signal Recorder.....	28
SenseWear Armband	29
<i>Self-Report and Direct Observation.....</i>	29
ASSESSMENT OF SLEEP.....	30
<i>Polysomnography (PSG)</i>	31
<i>Actigraphy</i>	32
<i>SenseWear Armband.....</i>	33
<i>Modular Signal Recorder.....</i>	35
<i>Subjective tools: questionnaires, diaries, logs, surveys, and interviews.....</i>	35
<i>Sleep Quality Measures</i>	36
SUMMARY	37
CHAPTER III: SUBJECTIVE AND OBJECTIVE METHODS TO EXAMINE THE RELATIONSHIP BETWEEN SLEEP AND BODY WEIGHT IN CHILDREN AND ADULTS.....	47

ABSTRACT.....	47
INTRODUCTION.....	48
METHODS.....	49
RESULTS.....	53
DISCUSSION.....	54
TABLES AND FIGURES	59
REFERENCES	64
CHAPTER IV: AN OBJECTIVE MEASUREMENT OF SLEEP ACROSS THE LIFE CYCLE IN FEMALES.	66
ABSTRACT.....	66
INTRODUCTION.....	67
METHODS.....	70
DATA ANALYSIS	72
RESULTS.....	72
DISCUSSION.....	73
TABLES AND FIGURES	76
REFERENCES	80
CONCLUSIONS	82
APPENDIX A: SLEEP AND BODY WEIGHT STUDY RECRUITMENT AND CONTACT MATERIALS	84
APPENDIX B: SLEEP AND BODY WEIGHT CONSENT/ASSENT FORMS	85
APPENDIX C: SLEEP AND BODY WEIGHT SLEEP LOG	95
REFERNES	97
ACKNOWLEDGEMENTS	108

CHAPTER I: INTRODUCTION

The increasing prevalence of overweight and obese individuals in the United States makes it imperative to study the various causal factors of obesity. Overweight and obesity are typically thought to be caused by an energy imbalance and a majority of research efforts today focus on studying strategies using diet and physical activity to reduce obesity. Unfortunately, despite decades of effort the struggle with obesity continues for many. Other putative causes of obesity such as sleep quantity and quality need to be further explored. With the causes of obesity being multifaceted, it is important to look beyond energy imbalance and find new clues for solving the obesity puzzle.

In order to explore the relationship between obesity and sleep, we have designed two studies and will explore this relationship in both prospective and retrospective ways. In the first prospective study, we compare sleep, body weight, and physical activity in children and adults using both objective and subjective tools. There is extensive evidence showing familial relationships with obesity. Sleep patterns and habits may also have ties to the family. Our first objective of the study is to compare sleep amounts in children and adults using these methods. Our second objective is to explore the relationship between sleep amount and body adiposity in the families. We will compare two new objective measures of sleep with a subjective method (sleep log). We hypothesized that the sleep assessment tools will report similar sleep amounts in children and adults. In our second study, we retrospectively examined sleep across the life cycle in females including women who are pregnant. This was a cross-sectional study. We used an objective

measure to compare bed times, wake times, and sleep amounts in pregnant compared to non-pregnant women. We hypothesize, that pregnant females will have shorter sleep duration, especially at the later measurement period of 35 weeks gestation, compared to non-pregnant females due the added physical discomfort of pregnancy.

This thesis will begin with a literature review focused on obesity, sleep, body composition assessment, physical activity assessment, and sleep assessment. The following sections include the family study manuscript and the female study manuscript each of which includes an abstract, introduction, methods, data analysis, results, and discussion for each manuscript. Following the manuscripts are the conclusions, appendices, references, and acknowledgements.

CHAPTER II: REVIEW OF LITERATURE

Introduction

This literature review provides a summary of information related to obesity and sleep. It also provides a review of current knowledge focused on assessment of body fat, physical activity, sleep quality, and sleep duration. To gain more information about the relationship between sleep, physical activity, and obesity, we explored the use of traditional and novel tools to measure sleep and physical activity. Typically, accelerometers are used to assess an individual's physical activity level and predict energy expenditure, however they can also provide useful information about sleep. Sleep surveys or logs have traditionally been used to capture information about sleep amount and patterns, and to understand sleep quality and other factors that could influence sleep such as technology, environment, diet, medications, health conditions, smoking, and caffeine and alcohol consumption (NSF 2011). In the studies completed as part of Iowa State University's Master of Nutritional Sciences graduate program, two accelerometer-based systems, the MSR145 (MSR Electronics GmbH, Zurich, Switzerland) and the SenseWear Mini Armband (Model: MF-SW, BodyMedia Inc., Pittsburgh, PA) were used to gather information related to sleep in children and adults.

Overview of Obesity

Prevalence of Obesity

Obesity is defined as excess body adiposity. Body mass index (BMI) is used as a screening tool for classifying an individual's weight as underweight, normal weight,

overweight, or obese. The growing obesity epidemic in the United States and worldwide continues to be of concern (Caballero 2007). In 2009, 36.2% of the nation was overweight and 27.2% was obese. For Iowans the numbers are comparable with national data, with 38.7% being overweight and 28.5% classified as obese. This information from the Behavioral Risk Factor Surveillance System is self-reported via a telephone survey and is collected monthly (BRFSS 2009). National Health and Nutrition Examination Survey data shows that obesity has more than doubled for adults (14.5 to 34.3%) and more than tripled for children (5 to 16.9%) when comparing the survey periods 1971 to 1974 and 2007 to 2008 (Ogden et al. 2010a,b).

Causes and Consequences of Obesity

The primary function of adipocytes is to store energy as triacylglycerides. Obesity results when energy input exceeds energy expenditure and causes hypertrophy and hyperplasia of adipocytes (Otto and Lane 2005). Obesity research typically focuses on diet and exercise as the causes of obesity. Other factors that can influence energy intake and expenditure and cause obesity include “, epigenetics, increasing maternal age, greater fecundity among people with higher adiposity, sleep debt, endocrine disruptors, pharmaceutical iatrogenesis, reduction in variability of ambient temperatures, and intrauterine and intergenerational effects” (McAllister et al. 2009). These later factors have received considerably less attention in relation to obesity, especially when research funding is the metric.

Being overweight or obese is a risk factor for a wide array of health problems, which include cardiovascular disease, diabetes, cancer, hypertension, stroke, respiratory

problems, and sleep apnea (CDC 2011a). Moderately obese individuals have an average life expectancy of 2 to 5 years less than those who are not overweight or obese. Severely obese individuals have a life expectancy up to 20 years less than those not overweight or obese (NIH 2005). The increased rates of hypertension, diabetes, and dyslipidemia could shorten longevity by as much as 5 years in the US (Wyatt et al. 2006). The causes and consequences of obesity create a complex relationship which makes it vital to look beyond diet and physical activity and to examine sleep more closely. Expanding research efforts in new areas by conducting more randomized clinical trials could help to better our understanding of obesity, its causes and preventative measures.

Overview of Sleep

Sleep in General Population

Lack of a good night's sleep results in a variety of negative health and cognitive issues, which makes it critical to study the prevalence of sleep deficiency and its effects on an individual's physical and mental health. The National Sleep Foundation has been conducting yearly telephone sleep surveys since 2002 focusing on different topics such as women and sleep, teens and sleep, technology use and sleep as well as many other topics. The polls usually consist of around 1000 individuals. The 2005 NSF survey found that only 26% of American adults were obtaining 8 or more hours of sleep. In the 2009 sleep poll, four in ten American adults agreed that sleep is more important than or equally as important compared to diet and exercise. According to the 2011 poll, 43% of Americans between the ages of 13 and 64 said they rarely or never get a good night's sleep on weeknights with 60% saying they experience a sleep problem every night such as waking

up in the middle of the night, too early, or un-refreshed. Most respondents said they need 7.5 hours of sleep a night to feel their best, but reported getting only an average of 6.9 hours of sleep a night. The poll used the Epworth Sleepiness Scale found that “baby boomers” are less sleepy than the younger generation, with 13-18 year olds being sleepier. Respondents between the ages of 13-18 years old reported getting an average of 7 hours and 26 minutes of sleep on weeknights, which is 45 minutes less than the 9.25 hours recommended by the NSF. Results from the 2006 NSF poll reported that 45% of adolescents ages 11 to 17 are getting less than 8 hours of sleep a night with adolescents tending to get less sleep as they get older, with 6th graders getting 8.4 hours a night and 12th graders getting 6.9 hours a night. The survey also showed that Americans are coping with sleepiness by drinking caffeinated beverages and taking naps (NSF 2011).

Sleep in Women

The 2007 National Sleep Foundation poll focused on sleep and women by surveying 1,003 American women between the ages of 18-64. Pregnant and post-partum women were also surveyed to investigate women’s sleep during different reproductive stages. It was discovered that 60% of women get a good night’s sleep a few days a week or less. Overall, 67% percent of women experienced sleep problems at least a few nights each week of which 46% experienced sleep problems every night. Not surprisingly, 72% of working mothers and 68% of single working mothers were more likely to experience sleep problems than women without children. The factors that most commonly disturbed women’s sleep were pets (17%), providing childcare (20%), and noise (39%). A poor night’s sleep lead to daytime sleepiness which caused women to experience high stress

(80%) and spend less time with family and friends (39%). Of the women who were of childbearing age, 67% said they experienced insomnia a few days a week with 33% saying their sleep cycle is disturbed during the week of their menstruation. Pregnant women (84%) said they experience insomnia a few nights a week and 30% said they rarely or never get a good night's sleep and post-partum women had the same rate of insomnia (NSF 2007). The high rates of sleep deprivation in women and the general population makes it of the utmost importance to investigate the causes and consequences of sleep loss.

Causes and Consequences of Sleep Loss

Sleep is influenced by a variety of factors including age, sex, food, and physical and psychological health. The importance of factors influencing sleep differs based on an individual (Buysse et al. 1989). Sleep loss is becoming increasingly prevalent in today's society due to factors such as technology use, environment, diet, medications, health conditions, smoking, shift work, and caffeine and alcohol consumption. Ecological reasons for increased sleep debt include "insomnia, stress, social pressures, desire to get more work accomplished, night-shift work, medications used to treat colds, allergies, pain, cardiovascular problems, and late-night TV viewing and internet use" (McAllister et al. 2009). The 2011 NSF poll explored the connections between communications technology use and sleep and 95% reported that they used some type of technology at least a few nights a week within the hour before going to bed. Technology use provides stimuli that keeps individuals awake past their natural bed time. The use of technology devices such as televisions, computers, videogame systems, or cell phones was found to

be more prevalent in younger survey respondents. The only exception to this was television viewing which was higher for the older generation, 46-64 year olds. Examination of survey data showed that children's morning waking times have stayed constant while bedtimes have become later in the evening (Iglowstein et al. 2003).

NSF found that an overwhelming 74% of employed adults over the age of 30 said that their sleep loss has a negative impact on their job performance and 19% of adults said that their intimate or sexual relations were also negatively affected by sleepiness (NSF 2005). Effects of sleep deprivation include a increase reaction time and decrease the ability to hold attention and retain information (Goel et al. 2009). Ferrie et al. (2007) found higher rates of all-cause mortality among participants who report short sleep (≤ 5 hours) or long sleep (≥ 9 hours). The association between sleep and mortality is seen in about half of the studies. The myriad of health and cognitive issues associated with sleep loss make it extremely important to get an adequate night's sleep daily and with today's complex, technology-rich environment achieving this is especially challenging for adult and children alike.

Public Health Recommendations

The National Sleep Foundation recommends that children between the ages of 5 and 10 should sleep 10 to 11 hours a night, teens ages 10 to 17 need to sleep between 8.5 and 9.25 hours whereas adults should sleep 7 to 9 hours a night (NSF 2011b). The National Sleep Foundation recommends having good sleep hygiene that ensures normal, quality nighttime sleep and full daytime alertness. Sleep hygiene includes setting a sleep schedule, exposing yourself to bright light early in the morning while avoiding it at night,

exercising regularly, establishing a relaxed bedtime routine, and creating a cool and comfortable sleep environment. It is also important to avoid caffeinated beverages, tobacco, chocolate, large meals, alcohol, and medications that disrupt sleep before bedtime. The NSF also recommends that naps should be limited to less than 45 minutes and take place before 3:00 pm.

Despite the NSF recommendations, Marshall et al. (2008) found that the evidence is not yet strong enough to give public health advice on sleep duration to be used as a modifiable risk factor for obesity. While it is still important to get adequate sleep due to the numerous harmful effects associated with a lack of sleep, *there is currently no data showing that change in sleep duration results in weight loss.*

Overview of Sleep and Obesity

The trend of decreasing sleep is evident when comparing that American adults slept 8.7 to 9 hours a night before World War I, whereas Americans more recently slept 6.7 hours a night in 2009 (Figure 1). McAllister et al. (2009) provides epidemiological evidence in adults linking the decreasing amount of average sleep to increasing percent of U.S. population that is obese (Figure 1). Below, the studies in children, adults, and possible mechanisms of sleep deprivation and obesity provide further insight into this topic.

Studies in Children

Cross-sectional, cohort, and prospective studies in children reveal that short sleep duration is strongly associated with obesity. Data from prospective longitudinal studies

in children (Table 1) showed that shorter sleep durations were associated with increased BMI, being overweight and increased obesity risk. Table 3 includes cross-sectional sleep and weight studies in children. A study of 8,274 Japanese children between the ages of 6 and 7.7 years old found that compared to children with sleep duration of 10 hours or more had an odds ratios (OR) for obesity of 1.49, 1.89, and 2.89 for sleep durations of 9–10, 8–9, or fewer than 8 hours, respectively (Sekine et al. 2002). Padez et al. (2005) conducted a study of 4,511 Portuguese children ages 7–9 and found that sleep duration of 8 hours and 9–10 hours had ORs for obesity of 2.56 and 2.27 respectively, when compared with 11 hours or more (Padez et al. 2005). A study of 422 Canadian children ages 5–10 found that compared to sleep duration of 12 hours or more, the ORs for obesity were 1.42 and 3.45 for sleep durations of 10.5–11.5 hours and 10 or fewer hours, respectively (Chaput et al. 2006). *All of the studies in children mentioned thus far assessed sleep using subjective measures such as logs, interviews, surveys, and questionnaires.*

Few studies have measured sleep objectively (described in the assessment of sleep section). Gupta et al. (2002) measured sleep duration with wrist actigraphy over a 24-hour period in 383 children aged 11–16 and found that the odds of obesity increased 5-fold for every hour reduction in sleep duration. Benefice et al. (2004) assessed sleep duration using an uniaxial CSA (Computer Science and Applications Inc., Shalimar, FL, USA) model 7164 accelerometer worn near the hip to assess sleep over 3–4 days in 40 Senegalese girls aged 13–14 years. Every 6.85 minute reduction in sleep increased BMI by 1 kg/m².

Studies suggest that boys may be more susceptible to sleep loss than girls because there is a stronger association between less sleep and obesity in males. It was found that the OR for obesity associated with sleep duration less than 8 hours compared to greater than 10 hours was 5.5 in boys and 2.1 in girls (Sekine et al. 2002). Additionally, the OR for obesity associated with sleep duration of 10 or fewer hours compared to 12 or more hours was 5.7 in boys and 3.2 in girls (Chaput et al. 2006). Also, it was found that each hour reduction in sleep duration increased the risk of being overweight by 10% in boys, but no significant relationship was found in girls (Knutson et al. 2005). The strong correlation between sleep debt and obesity is also found in some adult studies.

Studies in Adults

Longitudinal and cross-sectional sleep studies in adults are listed in Tables 2 and 4, respectively. The definition of normal sleep duration varied greatly across studies. The findings in adults regarding sleep and weight are less consistent than in children. Cross-sectional analyses of adults showed mixed results in finding an independent association between short sleep duration and increased weight gain. Some studies showed a relationship between short sleep duration and increased weight. Some studies found no association, a U-shaped relationship, or a relationship in only one sex (Table 4). One study found short sleep duration was associated with reduced weight (Tamakoshi 2004).

Vorona et al. (2005) found that in 900 overweight patients, increasing BMI was associated with decreased hours of self-reported sleep per day. In 3,158 individuals, those who slept 6 or fewer hours were at highest odds of being obese (Singh et al. 2005).

Patel et al. (2006) reported that in 68,000 U.S. nurses followed over a 16 year period, those sleeping 5 to 6 hours a night gained significantly more weight than did those getting 7 to 9 hours of sleep per night. A study of 990 employed adults in Iowa found that BMI increased by 0.42 kg/m^2 for each hour that average daily sleep decreased (Kohatsu et al. 2006). Gortmaker et al. (2005) found no association between sleep and body weight. Kripke et al. (2002) found a U-shaped association between sleep duration and BMI among women with the minimum at 7 hours. There was an association in men with longer sleep duration associated with a lower BMI. Overall, the cross-sectional data in adults suggest that the results are mixed and more research is needed. If this relationship is U-shaped, studies that force a linear relationship when modeling would underestimate the true effect of short sleep duration and may contribute to the negative findings in some studies. Findings on differences in sex susceptibility are also mixed. Some studies suggest a stronger relationship between sleep and obesity in women (Kripke et al., 2002, Cournot et al., 2004, Chaput et al., 2007, Vorona et al., 2005), and some found an association in men only (Ko et al., 2007).

Adult longitudinal studies found a positive relationship between sleep duration and weight, though this relationship decreased with age. The mixed findings in adult studies may be due to a more complex relationship between sleep duration and weight in this age group. The more negative findings in adults suggest that the relationship between sleep duration and weight may weaken with age. The cross-sectional relationship between sleep duration and weight weakened as participants grew older (Hasler et al. 2004) and the association between short sleep duration and weight was mostly seen in the youngest age group, ages 27 to 29. Overall, the studies suggest that

short sleep duration may contribute to weight gain and obesity, especially in children. An exploration into the mechanisms of sleep and obesity in adults and children in families may provide insight into understanding this relationship.

Possible Mechanisms of Sleep and Obesity

Several studies have attempted to assess possible mechanisms that link sleep and obesity. As shown in Figure 2, sleep deprivation may lead to increased caloric intake due to increased hunger and/or increased opportunity to eat. It is also possible that sleep deprivation could cause decreased energy expenditure through altered thermoregulation and increased fatigue (Patel et al. 2008). Altered thermoregulation refers to a drop in body temperature seen with sleep deprivation. Sleep deprivation is found to even decrease thyroid stimulating hormone when energy intake and activity level are constant. The relationship between sleep and obesity is difficult to determine as sleep disorders could also contribute to lack of sleep and increased obesity, or obesity related health problems may cause difficulty sleeping.

Lack of sleep is a risk factor for obesity since it affects glucose metabolism and upregulates appetite (Knutson et al. 2007a). Young men limited to 4 hours of sleep a night for 6 days had a 40% decrease in the rate of glucose clearance and a 30% decrease in insulin response (Spiegel et al. 1999). This diabetic-like response to sleep deprivation is one possible mechanism linking sleep to obesity (Knutson et al. 2007a). A meta-analysis by Cappuccio et al. (2010) found that not only quantity but also quality of sleep significantly predicts the risk of developing type 2 diabetes.

Another proposed mechanism is that sleep debt decreases leptin, a hormone secreted by adipose tissue and is involved in signaling satiety. A decrease in leptin thus leads to increases in hunger (Ahima and Antwi 2008). It was found that individuals getting 5 hours of habitual sleep is associated with 15.5% lower leptin levels when compared to those habitually getting 8 hours of sleep (Taheri et al. 2004). Chaput et al. 2007 also found that short sleep duration was associated with suppressed leptin. Simon et al. (1998) found that plasma leptin reaches a maximum midway through the normal sleep period. The increase in hunger is also partly due to an increase in plasma ghrelin, a hormone that is secreted by the stomach (Ahima and Antwi 2008). It was found that individuals getting 5 hours of habitual sleep had 14.9% higher ghrelin levels than individuals getting 8 hours of habitual sleep (Taheri et al. 2004). Spiegel et al. (2004) reported that young men who had sleep restricted for two consecutive nights had a 28% increase in plasma ghrelin levels compared to two consecutive nights of 10 hrs in bed.

Even though hormonal changes in the body are found, the studies that used food frequency questionnaires to estimate total caloric intake (Patel et al., 2006, Reilly 2005, Agras 2004) and intake of particular food groups (Patel et al., 2006, Reilly et al., 2005) found that the relationship between sleep duration and weight was weakened by controlling for diet. Von Kries et al. (2002) also used a food frequency questionnaire and found no relationship between sleep habits and caloric intake. All of these changes in insulin, leptin, ghrelin, and thyroid stimulating hormone could increase obesity due to decreased satiety, increased appetite, and decreased energy utilization. More studies that assess both appetite hormones and food consumption are needed to better understand this relationship.

Another mechanism of obesity may be sleep related disorders such as sleep-induced apnea, which refers to “intermittent, cyclical cessations or reductions of airflow, with or without obstructions of upper airway” (Dempsey et al. 2010). Sleep apnea has been linked to increased hypertension, insulin resistance, and appetite stimulating plasma neuropeptide Y (Tasali and Van Cauter 2002). Young et al. (1993) found that sleep apnea is significantly more prevalent in the obese population and that the disturbance in endocrine health may further exacerbate the problem in these individuals (McAllister et al. 2009). The causal relationship between sleep apnea and metabolic syndrome has been difficult to determine (Dempsey et al. 2010).

In addition to the hormonal mechanism and sleep apnea, sleep and obesity may be linked to motor activity. The rationale here is that sleep debt causes tiredness which leads to decreased activity and weight gain (Taheri et al. 2007) however Fogelhom et al.(2007) found that controlling for physical activity did not influence the association between sleep debt and obesity. Patel et al. (2006) found that independent of physical activity level, women who self-reported to be short sleepers were more likely to gain weight. Hasler et al. (2004) found that this association persisted after controlling for physical activity. Sleep-weight association was not explained by differences in physical activity (Heslop et al., 2002, Cournot et al., 2004, Chaput et al., 2007). Lauderdale et al. (2006) found no association between sleep duration and BMI and also found no relationship between sleep duration and physical activity. All of this data was based on subjective sleep questions and not on objective methods. Gupta et al. (2002) used actigraphy and Benefice et al. (2004) used accelerometry to assess physical activity and sleep, and they did not find a relationship between sleep duration and physical activity.

Further research into sleep and physical activity level within a family environment may provide insight into this area.

Assessment of Body Fat

Due to a rise in obesity, it is important to accurately assess body composition and specifically body fat in individuals. Studying body composition allows researchers to characterize populations, study age, sex, and racial differences, and provide public health advice. Body composition also provides a basis for reference to compare an individual to the general population. The tools for body fat assessment that will be discussed are hydrostatic weighing (HW), BOD POD® and body mass index (BMI)

Hydrostatic weighing

Hydrostatic weighing is the gold standard for assessing body fat (Fields et al. 2002). It works on the principle of density of an object equaling the mass divided by volume. Since body volume is difficult to measure due to the irregular shape of the body, it can be estimated using Archimede's principle which states that the volume of an object submerged in water is equal to the volume of the water displaced by that object. Density of the body is classified as fat and fat free body mass, which includes protein, water, and bone. It is assumed that fat free body mass is relatively constant between individuals and the value of a standard reference man is used. This is a limitation as the standard value is based on a limited number of cadavers and not appropriate for pregnant women, disabled, elderly, obese and infants. In addition, error is increased as most systems do not measure residual lung volume under water or at all. Limited availability of the equipment and

technical difficulty make HW a challenge and not appropriate for clinical practice (Dempster and Aitkens 1995).

BOD POD®

BOD POD® (COSMED USA, Inc, Concord, CA) is based on the two-compartment model of body composition assessment, which divides the body into fat and fat free mass. The BOD POD® uses whole body density of mass per volume to assess body fat. A scale is used to measure an individual's mass. The various approaches to measuring body volume include: hydrostatic weighing, helium dilution, air displacement plethysmography and acoustic plethysmography (Dempster and Aitkens 1995). The BOD POD® uses air plethysmography to measure body volume and plethysmography refers to measurement of size (Fields et al. 2002). Air plethysmography has been used to measure body composition for a century, but it wasn't until the mid-1990s that it was developed for more routine use (Dempster and Aitkens 1995). Currently there is only one commercially available system of air plethysmography for adults and children ≥ 2 years of age, the BOD POD®, and for infants up to 8 kg, the PEA POD® (COSMED USA, Inc, Concord, CA). The BOD POD® is based on the concept of Boyle's law that pressure and volume are inversely proportional to one another.

$$P_1/P_2 = V_1/V_2 \quad (1)$$

It measures the volume of an individual indirectly by measuring the volume of air that has been displaced in the chamber, also called a plethysmograph, by the individual. The BOD POD® measures lung volume as the subject breathes normally during the test. The air in the lungs, referred to as the thoracic gas volume (V_{TG}), can be either measured

or predicted. V_{TG} is measured at midtidal exhalation. The BOD POD® is divided into two chambers, the test chamber and the reference chamber having volumes of 450 and 300 L, respectively. Between the two chambers is an oscillating diaphragm that produces sinusoidal volume perturbations leading to small pressure changes within the chambers of approximately 1 cm of water (Fields et al. 2002). The air between the two chambers is mixed to keep the gas composition and to keep the γ in the pressure volume relationship unchanged. γ is the ratio of the specific heat of a gas at constant temperature and pressure. γ is approximately 1.4 for air. Equation 1 is used for isothermal conditions and equation 2 is used for adiabatic conditions (Daniels and Alberty 1967).

$$P_1/P_2 = (V_1/V_2)^\gamma \quad (2)$$

Body volume is measured by first calibrating the chamber both empty and then with a 50 L or 20 L standard. The test is conducted under adiabatic conditions, but there is some volume of air in the lungs, near the skin, hair, and clothes that need to be adjusted since isothermal air volumes are compressed 40% more than adiabatic air volumes. Adiabatic air refers to air that freely gains and loses heat during compression and expansion. Since isothermal air is more compressible, it leads to an underestimation of body volume. Isothermal air can be minimized by wearing minimal clothing which includes a swimsuit and compressing hair with a swim cap (Dempster and Aitkens 1995). The BOD POD® was initially developed for isothermal conditions though more recently Poisson Law with γ has been used to adjust the pressure volume ratio for adiabatic conditions (Equation 2). BOD POD® tests should be done when the subject is completely dry and in a rested state. Moisture on the body and hair will incorrectly

increase body weight and recovering from an elevated metabolism state will alter breathing patterns.

$$\text{Body Volume}_{(\text{Corr})} (\text{L}) = \text{Vb}_{\text{raw}} (\text{L}) - \text{SAA} (\text{L}) + 40\% \text{ V}_{\text{TG}} (\text{L}) \quad (3)$$

$$\text{Body Density} = \text{Mass} / \text{Vb}_{\text{Corr}} \quad (4)$$

$$\text{SAA} (\text{L}) = k(\text{l}/\text{cm}^2) * \text{BSA} (\text{cm}^2) \quad (5)$$

$$\text{BSA} (\text{cm}^2) = 71.84 * \text{weight} (\text{kg})^{0.425} * \text{Height} (\text{cm})^{0.725} \quad (6)$$

Body density (D_b) is calculated using the formula $M/\text{Vb}_{\text{corr}}$, with Vb_{corr} being the body volume corrected for surface area artifact (SAA) and V_{TG} , the thoracic gas volume (Equation 3 and 4). Body surface area (BSA) in equation 6 is calculated using body weight and height (Dubois and Dubois 1916). Body volume of the subject is measured as Vb_{raw} , which has not been corrected for V_{TG} and surface area artifact (SAA). This step is repeated and if the measurements are within 0.2% or 150 mL, they are averaged. A third test is done if the values are not in this range and the two closest values are averaged. Disagreement between the Vb_{raw} values could be due to movement, pressure changes, air drafts, yawning, coughing, throat clearing, or breath holding. Finally V_{TG} is measured or predicted.

During the measurement of V_{TG} , the subjects take a few normal tidal breaths while wearing a nose clip and breathing room air through a disposable tube and antimicrobial filter. Then a shutter valve in the airway closes for 2 s, during which the subject makes a few quick puffs. The changes in the airway produces changes in the chamber pressure and are used to calculate V_{TG} via proprietary methods. It is often difficult for subjects to follow this procedure; resulting in V_{TG} predicted to be used (Fields et al. 2002).

Body density (D_b) is then used to estimate percent body fat (% fat) based on 2 compartment models of Siri (1961) or Brozek et al. (1963) for whites. The Siri equation is used for the general population. The Schutte et al. (1984) equation is used for the general population of African American and Black males. The Ortiz et al. (1992) equation is used for African Americans and Black females. The Brozek et al. (1963) equation is used for lean and obese individuals, and the Wagner and Heyward (2001) equation is used for Black males. The previous equations are used for adults, and the Lohman (1986) equation is used for children younger than or equal to 17 years of age. The various equations to estimate % body fat are shown in Table 5.

The BOD POD® is very reliable when measuring volumes of inanimate objects on the same day or different days (Fields et al. 2002). Testing a linear wide range of volumes that approximate human size (25-150 L) using a series of cubes had a regression equation of $y = 0.9998x - 0.274$, $r^2 = 1.00$, SEE = 0.004 l (Dempster and Aitkens 1995). McCrory et al. (1998) found that there was no significant difference between V_{TGmeas} vs V_{TGpred} . McCrory et al. (1995) found that no significant difference between the first and second trials of %fat in adult subjects (20-45 years) which showed the reliability of the BOD POD®. The reliability for % fat by BOD POD® had a mean within subject coefficient of variation from 1.7% to 4.5% within day and from 2.0 to 2.3% between days for adults. In children, the precision of 2 repeat measures of %body fat was 0.83% for 11 boys (mean = 12.6%) and 0.99% for 16 girls (mean = 19.7%). Assessing % fat in 30 men (mean = 18.0% fat) and women (mean = 27.5% fat) had similar precision values of 0.99% and 0.76% body fat, respectively. Dewit et al. (2000) and Wells et al. (2000) also reported that body volume precision for children 7 to 14 years of age was as good as

adults. Miyatake et al. (1999) reported similar mean coefficient of variations for within day and different days for % fat.

It has been found that the average mean differences in BOD POD® and HW agree within 1% body fat for adults and children. There was no significant difference between %fat from BOD POD® compared to HW for either sex and both sexes combined (McCrory et al. 1995). Two studies reported that the precision of the BOD POD® body volume was better than HW in adults when V_{TG} predicted was used for the BOD POD® and submersion lung volume was measured for HW (Dewit et al. 2000 and Wells et al. 2000).

The advantages of the BOD POD® include that it is fast, automated, non invasive, safe, and can be used for a diverse range of populations. After calibration is complete, a test typically takes a couple of minutes to run. The BOD POD® can be used for individuals weighing up to 550 pounds. A disadvantage could be that wearing minimal clothing could be uncomfortable and cause privacy issues for some. Another disadvantage is that measuring thoracic gas volume could be difficult, especially for children.

Body Mass Index (BMI)

Another tool for body fat assessment is the body mass index (BMI). BMI is calculated by the following equations:

$$BMI = 705 \times \text{Weight (pounds)} / \text{Height (inches)}^2 \quad (7)$$

$$BMI = \text{Weight (kg)} / \text{Height (meters)}^2 \quad (8)$$

Non-nutritional factors such as food, feces, and fluid can cause variability in weight (Zerfas 1979). Height is relatively stable and not often influenced by short term deficits in nutrition (Yarbrough et al. 1974). For adult men and women the classifications are underweight ($\text{BMI} < 18.5 \text{ kg/m}^2$), normal weight ($\text{BMI} 18.5\text{-}24.9 \text{ kg/m}^2$), overweight ($\text{BMI} 25\text{-}29.9 \text{ kg/m}^2$), and obese ($\text{BMI} \geq 30 \text{ kg/m}^2$) (Caballero 2007). BMI is calculated using equations the same way for adults and children, the difference being that the CDC BMI-for-age growth charts translate the BMI number into a percentile for children, which takes into account sex and age. For adults the BMI criteria are age and sex independent. The child BMI chart should be used for ages 2 to 20 years. For children, less than 5% is considered underweight, between 5% and 85% is considered normal weight, between 85% and 95% is considered overweight, and greater than 95% is considered obese. BMI is used as a screening tool and not a diagnostic tool for excess body fat (CDC 2011bc).

BMI is studied using indices of diagnostic performance such as sensitivity and specificity. Sensitivity is “the probability that a person who actually has a condition of interest will have a positive test result,” which is a true positive. Specificity is “the probability that a person who does not have a condition of interest will have a negative test result,” which is a true negative. A meta-analysis assessing the diagnostic performance of BMI found that BMI has good specificity but poor sensitivity in identifying excess adiposity. Poor sensitivity leads to individuals with excess body fat being labeled as non-obese. A limitation of BMI is that low sensitivity refers to under diagnosing excess body fat. Another limitation of BMI is that it does not distinguish between fat and lean mass. An example of this is that a trained, athletic individual with a lean body mass may be misclassified as overweight when one’s body fat is in fact low.

Okorodudu et al. (2010) suggests that for maximum diagnostic performance for obesity the cut off for BMI is between 25 and 30 with there being a tradeoff between sensitivity and specificity. Lower cutoff values have high sensitivity and higher cutoff values have high specificity. The advantage of the BMI is that it is a low cost screening tool that can be used to provide body composition information for large groups.

Assessment of Physical Activity

Physical activity is a behavior defined as "any bodily movement produced by the skeletal muscle that results in energy expenditure (EE)" (Caspersen 1985). Physical activity is distinguished from exercise which is physical activity that is planned, structured, and repetitive (Welk 2002). Inactivity is associated with increased risk of dying prematurely and developing heart disease, diabetes, colon cancer and high blood pressure (2008 HHS PA guidelines report). Along with poor diet, physical inactivity is associated with increased risk of diabetes, high blood pressure, high cholesterol, asthma, arthritis, and poor health status (Mokdad et al. 2001). Low energy expenditure will increase the likelihood of being in a positive energy balance (Despres and Lamarche 1993) and may result in weight gain. Assessment of physical activity is a way to study health behaviors in a population and its association with diseases, mortality, and morbidity. It is important to have an accurate measure of physical activity as a way to monitor current levels and changes in a population. Studying physical activity also allows researchers to measure the effects of intervention studies related to physical activity (Prince et al. 2008). The American College of Sports Medicine (2008)

recommends that “Every U.S. adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week.”

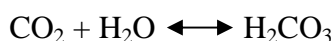
Physical activity can be assessed using subjective or objective tools. Subjective methods include questionnaires, diaries, logs, surveys, and interviews. Objective measures of physical activity include calorimetry, physiological markers, motion sensors, and direct observation. Motion sensors include heart rate monitors, accelerometers, and pedometers. Accelerometers will be discussed in greater detail below. The various tools to study physical activity result in a combination of indicators of activity level such as type, frequency, intensity, duration, volume, and metabolic equivalents. The tools for physical activity assessment have an inverse relationship between feasibility and validity. For example, diaries, self-reports, pedometers, heart rate monitors, accelerometers, direct observation, doubly labeled water, and indirect calorimetry are listed in the order of decreasing feasibility and increasing validity (Welk 2002).

Calorimetry includes indirect calorimetry, direct calorimetry, and non-calorimetric techniques. With indirect calorimetry, oxygen consumption and/or carbon dioxide production is measured, which is then converted to energy expenditure. Direct calorimetry measures the rate of heat loss from a subject to the calorimeter. Non-calorimetric techniques extrapolate physiological measurements to predict energy expenditure. Non-calorimetry includes doubly labeled water (DLW). Other non-calorimetry tools are physiological measurements such as heart rate monitoring, and physiological observations such as activity logs and accelerometers. It is important to have physical activity measures that are accurate and reliable (Caspersen 1989). This study used accelerometers (MSR145 and the SenseWear WMS® Mini armband) to

assess physical activity. There is no gold standard for directly assessing physical activity (Welk 2002).

Doubly Labeled Water

The doubly labeled water technique originates from a study conducted by Lifson et al. in the 1940s. In the doubly labeled water method, both oxygen and hydrogen can be labeled ($D_2^{18}O$) with stable non-radioactive isotopes. An optimal dose is determined based on body mass. The dose is consumed by the subject at baseline after collection of urine, blood, or saliva samples. Over time the isotopes equilibrate with bodily fluids to reach the following equilibrium:



The ^{18}O tracer distributes in body water, circulates as H_2CO_3 , and is expired as CO_2 . Oxygen in body water decreases as expired CO_2 increases and as body water is lost in urine, perspiration, and respiration. The D_2 tracer distributes in H_2O and H_2CO_3 , decreasing as body water is lost. Urine, blood, or saliva samples are collected for 7-21 days post doubly labeled water administration. Mass spectrometry is then used to measure D_2 and ^{18}O . The elimination rate difference of D_2 and ^{18}O is used to determine the rate of CO_2 production and calculate total daily energy expenditure. Doubly labeled water indirectly assesses physical activity by using the total daily energy expenditure in conjunction with resting energy expenditure and the thermic effect of diet. The main advantages of the doubly water method include its low error (~ 7%), easy administration, and minimal subject burden making it more representative of free-living situations (Levine 2005). Despite these advantages, the high cost of the ^{18}O isotope and the

complicated analysis using mass spectrometry limits widespread application of DLW (Jacobi et al. 2007).

Accelerometers

Acceleration refers to the change in velocity over time. Accelerometry detects body displacement electronically using piezo-resistive or piezo-electric motion sensors. Piezo-resistive accelerometers respond to change in acceleration by change in resistance of silicon resistors. This resistance is then transformed to a voltage proportional to the amplitude and frequency of the acceleration. Piezo-resistive accelerometers need an external power source and are able to respond to constant acceleration such as gravity. Piezo-electric accelerometers do not require a power supply and generate electric charge in response to a mechanical force such as acceleration (Plasqui and Westerterp 2007).

Accelerometers can detect body displacement with various degrees of sensitivity. The Caltrac is an uniaxial accelerometer that detects body displacement in one direction. The RT3, TritracR3D, Tracmor, MSR145, and SenseWear are examples of triaxial accelerometers that detect body displacement in three axes. The Actigraph is an omnidirectional accelerometer that detects body displacement in all directions. The accelerometer measures the acceleration of the body part it is attached to and not the absolute acceleration of the person. The criterion for accelerometer selection involves the total number of accelerometers needed, placement of the accelerometers, epoch length, the number of days of monitoring required for the study, and the cost of accelerometers (Trost 2005).

Accelerometer recordings results in raw signals that need to be filtered. High pass filters exclude low frequency signals and low pass filters exclude high frequency signals. An example of a low frequency signal is normal g force and an example of high frequency acceleration could be due to electrical interference. Human body accelerations range from -6 to +6 g with higher forces during impacts and landings (Plasqui and Westerterp 2007). Factors that can influence acceleration include body movement, gravity, external vibration, and movement of a loose sensor on the body. It is important to place the sensor in the same orientation consistently in the study as the output varies with different orientations.

Accelerometry data can be used to classify physical activity in various metabolic equivalents (METs) and physical activity levels (PAL). One MET represents resting energy expenditure and is equivalent to $3.5 \text{ ml O}_2 / \text{kg} / \text{min}$ and PAL is the total energy expenditure divided by basal metabolic rate (Welk 2002). Since basal metabolic rate is related to body weight, PAL is adjusted for body weight. Accelerometers can also be used to study patterns of physical activity over extended periods of time. This can include total amount, frequency, intensity, and duration of physical activity (Plasqui and Westerterp 2007).

Some advantages of accelerometers are that they are small, noninvasive, and can provide components of activity thermogenesis. A disadvantage is that accelerometers may not provide total daily energy expenditure as subjects are able to easily remove them when showering or swimming or due to non compliance, which makes it difficult to assess the physical activity cost of water-based activities (Welk 2002). Accelerometers

are better at quantifying physical activity levels between groups of subjects rather than for a given free-living subject (Levine 2005).

The cost of activity monitors can be high which limits their use with large samples. Other limitations of accelerometers include detecting with accuracy the acceleration of the body parts it is not worn on and activities such as, incline walking, load carrying, and other nonlocomotor movements such as twisting, bending, swaying, stretching, turning, and swinging. An accelerometer worn on the waist would not detect accurate activity during cycling, which makes it difficult to measure all activities equally. Also water-based activities cannot be assessed. Below is a further examination of the two accelerometer based systems utilized in the current studies (MSR145 and SenseWear).

Modular Signal Recorder

MSR is a triaxial accelerometer which is also capable of measuring temperature. The frequency of data collection can be set by the researcher. This device is used to collect raw acceleration data as voltages. The raw outputs can be used with non-proprietary algorithms and equations developed by the researcher to evaluate physical activity and energy expenditure in free-living subjects. The MSR sensor is worn at the waist and thigh, supported by lightweight clothing. The attachment location allows the researcher to use positional data to determine body position and for example separate sitting, standing, and lying time. The advantage of the MSR sensor is that it can measure the activity data for a whole day, which allows the researchers to study daily activity components as needed. A disadvantage is that the sensor must be recharged and

reprogrammed daily. However, depending on the sampling frequency, the battery capacity and memory can be extended to several days.

SenseWear Armband

The Sensewear Mini armband has been used by physical activity researchers since 2004. It contains a triaxial accelerometer which measures physical activity, as well as four heat sensors that monitor skin temperature and heat flux. It measures galvanic skin response because sweat gland activity from physical and emotional response makes skin more electrically conductive. Heat flux is the rate that heat dissipates from the body measured by the difference between skin temperature and near body ambient temperature. Because this device has multiple sensors that combine information to determine physical activity patterns, it is referred to as a pattern- recognition system. The most current models are worn on the upper left arm. All of these measures along with age, sex, height, and weight are used to calculate energy expenditure, metabolic equivalence, steps taken, physical activity, sleep duration, and sleep efficiency. An advantage of the armband is that it is simple and user friendly. The armband uses proprietary algorithms to report physical activity and sleep in hours and minutes. Like other accelerometers, a disadvantage of the armband is that the frequency of sampling and battery life has to be balanced in order to encourage subject compliance.

Self-Report and Direct Observation

Self-report measures include physical activity logs, diaries, and questionnaires. There are several self-report measures with adequate reliability and criterion validity for

adolescents and adults. A 2008 review by Prince et al. found that no clear trends were found when comparing physical activity monitoring by self-reported versus direct methods. Correlations between self-report and direct methods ranged from -0.71 and 0.96. Self report is useful because it is inexpensive and requires minimal participant involvement. The only equipment needed is a pencil and a piece of paper, and in some cases a computer. Issues with self report include that the subjects may misinterpret the questions or may have difficulty recalling the details of the physical activity performed. It is also possible that self report may fail to detect frequency, type, intensity, or duration. A concern with self report measures is the act of recording physical activity may influence a subject's behavior and may lead to higher than average physical activity levels for the subject during the assessment period. Direct observation includes trained observers to measure the behavioral aspects of physical activity. This method is more time consuming and expensive for the researcher and therefore is limited to small studies in specific settings over short periods of time (Welk 2002).

Assessment of Sleep

Sleep is defined as “a reversible state of perceptual disengagement and unresponsiveness to the environment, usually accompanied by quiescence and recumbency” (Bloch 1997). Approximately one-third of an individual's time is spent sleeping therefore it is important to understand the role that sleep may contribute to an individual's weight and overall health. Sleep can be measured using subjective and objective tools. Subjective tools include sleep logs, diaries, questionnaires, and sleep quality measures. Objective tools include polysomnography (PSG), actigraphy, and

accelerometers such as SenseWear Mini armband, and MSR145. Using accelerometers to study sleep as well as physical activity allow for faster data collection while minimizing cost and participant burden (Weiss et al. 2010). It is important to accurately assess sleep to study the relationship between sleep and other health issues.

Polysomnography (PSG)

Currently the gold standard for measuring sleep is polysomnography (PSG). PSG involves using multiple electrodes attached to participants while they sleep overnight in a research setting. PSG provides information about sleep quality by using several physiological measurements which may include respiratory monitoring, snoring and cardiac monitoring (Jafari and Mohsenin 2010). During sleep, periods of nonreticular eye movement (NREM) sleep, reticular eye movement (REM) sleep, and brief periods of wakefulness occur in 60 to 90 minute sleep cycles (Carskadon and Dement 1994). PSG is conducted in a sound proof, climatized, and completely dark room. Results of PSG include: total sleep time, sleep period time, wake time after sleep onset, duration of each stage, sleep efficiency, and number of arousals. Sleep efficiency refers to the ratio of total sleep time to total sleep period time per day in percent. The disadvantage to PSG is that it may disturb normal sleep patterns, especially in children (Iwasaki et al. 2010). This technique is also expensive, time consuming, and requires technical expertise. PSG needs to be performed for more than one night to adequately diagnose sleep disorders. However, sleep disorders related to external factors such as sleep hygiene or environment may not be adequately identified using PSG. For free-living situations, portable PSG is also used to study sleep, but this still requires a trained individual to interpret the results

(Jafari and Mohsenin 2010). There is good agreement between portable and laboratory PSG (Mykityn 1999).

Actigraphy

A tool for measuring sleep in free-living individuals is actigraphy and refers to devices worn on the wrist to measure movement activity. Actigraphy includes devices such the Actical, Sleepwatch, ActiTrainer, ActiSleep, and Actiwatch. In actigraphy, the different ways to transduce analog signals into digital signals result in very different activity counts for the same activity. Some actigraphs can allow subjects to vary recording parameters such as epoch length or sensitivity, which also affects the data. All of these variables make it difficult to make comparisons between different actigraphs and studies using actigraphs (Acebo and LeBourgeois 2006). Compared to PSG, Sleepwatch, Actiwatch, and Actical have been shown to be reliable (Weiss et al. 2010). In general epoch-by-epoch agreement and whole-night parameters agreement for sleep estimated by actigraph algorithm vs PSG is greater than 0.85 and 0.80, respectively. The largest difference between PSG and actigraphy involves transitions from wake to sleep and sleep to wake. Development of standardization for scoring actigraph recordings is needed (Acebo and LeBourgeois 2006).

The actigraph can be worn for up to a week, but a disadvantage is that it cannot tell the difference between being awake without movement and sleeping without movement (Yi et al. 2006). This makes it difficult to study sleep in individuals with movement related sleep disorders. Also, actigraphs do not provide information about sleep depth or quality (Miwa et al. 2007) and there is little evidence of actigraph validity

on many output parameters such as sleep onset latency, sleep bouts, wake bouts, and motionless sleep (Acebo and LeBourgeois 2006). There are few studies using actigraphy in children (Iwasaki et al. 2010).

SenseWear Armband

There is limited research on the use of the SenseWear pattern recognition system to study sleep. Sunseri et al's article published by Body Media Inc. (2005) discusses the older 2-axis accelerometer system to study normal sleep in ten subjects. It was found that SenseWear captured most sleep movements when compared with PSG and videotape of the sleep. These researchers also reported that the accuracy for predicting in and out of bed for free-living subjects was 93.2%. The minute by minute prediction of true positive sleep was 99.1% and true negative wake was 50.5%.

Miwa et al. (2007) developed a sleep quality score using data from the Sensewear Pro2 Armband. They divided sleep into two stages, deep sleep and light sleep. This was based on the number of rollovers which were decreased in deep sleep. The following equations were used with $T_4 = 20$ min.

$$\text{Deep Sleep: } R_i - R_{i-1} \geq T_4$$

$$\text{Light Sleep: } R_i - R_{i-1} < T_4$$

$$R_i: \text{Time of roll-over } (i > 1)$$

$$T_4: \text{Threshold (min)}$$

They postulated that the most important measure of sleep quality is sleep depth since it provides more refreshment from mental and physical fatigue than light sleep.

Evaluation value Q was designated as the sleep quality score. S_d is the deep sleep duration in minutes and S is the total sleep duration in minutes.

$$Q = S_d / S$$

They found that sleep quality decreases when sleep duration increases because only light sleep increases during the end of sleep. They also studied roll over detection and found that when compared with video camera recordings, the correct recognition rate was 82.5% and the correct detection rate was 84.2%. Correct recognition rate was defined as the ratio of correct detection to the total number of rollovers recorded by video camera. Correct detection rate was defined as the ratio of correct detection to the total number of roll-overs detected by algorithm. With a subject wearing the armband for 20 nights, it was found that 485 of 556 rollovers were detected when compared to video recordings. From the detected rollovers, 400 of these 485 were correct with 85 rollovers undetected and 75 false positives.

The SenseWear armband samples at a rate of one sample per minute. As mentioned earlier, the SenseWear pattern recognition system consists of a triaxial accelerometer, heat flux sensor, galvanic skin response sensor (GSR), skin temperature sensor, and a near-body ambient temperature sensor. SenseWear provides sleep data in terms of total sleep time and sleep efficiency. Though SenseWear does not define how sleep efficiency is calculated, a simple calculation showed that sleep efficiency in SenseWear is calculated with the formula of the ratio of total sleep time to total lying down time in percent. An advantage of the armband is that it can be worn for a week without having to be replaced or exchanged which requires less time commitment from the study participants.

Modular Signal Recorder

Currently there is limited research on the use of the MSR as a tool to study sleep. We hope to provide more insight in using MSR to study sleep. The MSR is worn on supporting clothing, near the body, and is able to provide acceleration data wherever it is placed. As mentioned above, the placement of the sensor also allows for body position determination which may offer an advantage over other accelerometer-based systems that may not include body position in determining sleep duration. The advantage of the MSR sensor is that it provides raw accelerometry data without processing it through proprietary algorithms. This data can then be processed through the researcher's own algorithms and equations can be applied to predict energy expenditure. The disadvantage of the MSR is that the subjects must put on new sensors each day so as to adequately capture the data and that the subjects must wear the shorts to which the MSR is attached. This requires more time commitment from the subjects since they need to be available to exchange sensors.

Subjective tools: questionnaires, dairies, logs, surveys, and interviews

Sleep logs, dairies and questionnaires provide subjective data on an individual's sleep. In using subjective assessment tools, there is a trade-off between quantity and quality of data collected due to subject burden (Iwasaki et al. 2010). To prevent response fatigue or carelessness, it has been suggested that the survey should take less than 20 minutes to complete (Rothman 1998). These tools can have responses that are dichotomous, Likert-type, or open-ended. Spruyt and Gozal (2011) also provided a list of

guidelines for designing a pediatric sleep questionnaire. Some well known sleep questionnaires include the Pittsburg Sleep Quality Index, the Epworth Sleepiness Scale, and the Berlin Questionnaire (Lauderdale et al. 2006).

Iwasaki et al. (2010) compared 7-day actigraphy in 5-year olds with parental reports and found that parental reports correlated well with actigraph even though sleep periods were longer in the parental reports. Gaina et al. (2004) found that high school children tend to overestimate sleeping hours, but the correlation between subjective sleep log and objective actiwatch was still high: 0.99 ($p < 0.001$) for sleep start time, 0.99 ($p < 0.001$) for sleep end time, and 0.97 ($p < 0.001$) for assumed sleep length. In middle aged adults it was found that subjective reports of habitual sleep are systematically over-reported. Compared to 3-day actigraphy, those who slept 5 hours reported, on average, 6.29 hours of sleep and those who slept 7 hours reported 7.31 hours (Lauderdale et al. 2008). Sleep logs are usually easy for subjects to complete and cost efficient. The benefit of self report is that it captures subjective data such as tiredness, sleepiness, and sleep quality.

Sleep Quality Measures

Due to the lack of an established definition, sleep quality is used to refer to many different sleep criteria such as total sleep time, sleep onset latency, degree of fragmentation, total wake time, sleep efficiency, and events disrupting sleep. The most widely used tool to assess sleep quality is the Pittsburgh Sleep Quality Index, which retrospectively provides sleep quality data for the past month for a subject. The index provides information regarding sleep duration, sleep latency, sleep disturbances, use of

sleep medication, and next day functioning. For an individual, sleep quality depends on the specific sleep concern that the individual is facing. An individual with difficulty falling asleep will rate sleep quality differently than an individual that has difficulty staying asleep. A possible approach to analyze sleep quality is to divide the subjects into subgroups and to carry out analyses separately in those groups. Another method is to group individuals by their most deviant sleep parameter (Krystal and Edinger 2002). Research on sleep quality is limited due to a lack of a standard definition. The SenseWear uses sleep efficiency as a measure of sleep quality.

Summary

The rates of obesity continue to increase worldwide. Obesity is a multifaceted disease that is influenced by many factors such as energy imbalance, increasing maternal age, medications, and sleep debt (McAllister et al. 2009). Being overweight and obese is a risk factor for health problems such as diabetes, hypertension, respiratory problems, and sleep apnea (CDC 2011a). Since obesity can lead to sleep apnea, it is difficult to extract which factor is the cause and which is the effect. Nonetheless, most research shows that there is an association and that further research is needed to understand this association. McAllister et al. (2009) in Figure 1 shows an inverse relationship between decreasing amounts of sleep since World War I and increasing amounts of obesity. The most recent sleep poll by the National Sleep Foundation (2011) found that 43% of Americans between the ages of 13 and 64 say they rarely or never get a good night's sleep on weeknights. The 2007 National Sleep Foundation poll found that 60% of women get a good night's sleep a few days a week or less. The same poll also mentioned that 84% of

pregnant women said they experience insomnia a few nights a week and 30% said they rarely or never get a good night's sleep. The causes of poor sleep include technology use, environment, diet, medications, health conditions, smoking, shift work, and caffeine and alcohol consumption. Poor sleep can lead to many health and cognitive issues such as diabetes, obesity, hypertension, decreased attention span and reaction time (Goel et al. 2009). The increasing prevalence of poor sleep and its myriad of negative consequences make it vital to study the relationship between sleep and obesity, using reliable and valid tools. An area of exploration is the use of physical activity measurement devices to study sleep. Using physical activity tools to also study sleep allows for the gathering of more information from one tool, decreasing cost, and decreasing participant burden.

This thesis contains two studies performed at Iowa State University as part of the Nutritional Sciences graduate program. The purpose of the studies is to use subjective and objective methods to study sleep and its relationship to body weight and physical activity. The first study focused on studying sleep with children and adults in families using one subjective method (sleep logs) and two objective methods (SenseWear pattern recognition system and MSR accelerometer). The second study looked at sleep comparisons between pregnant and non-pregnant women and in general across the lifespan of women. The following chapters present two separate scientific manuscripts for submission to a scholarly journal in the field of nutrition, physical activity, obesity, and/or sleep.

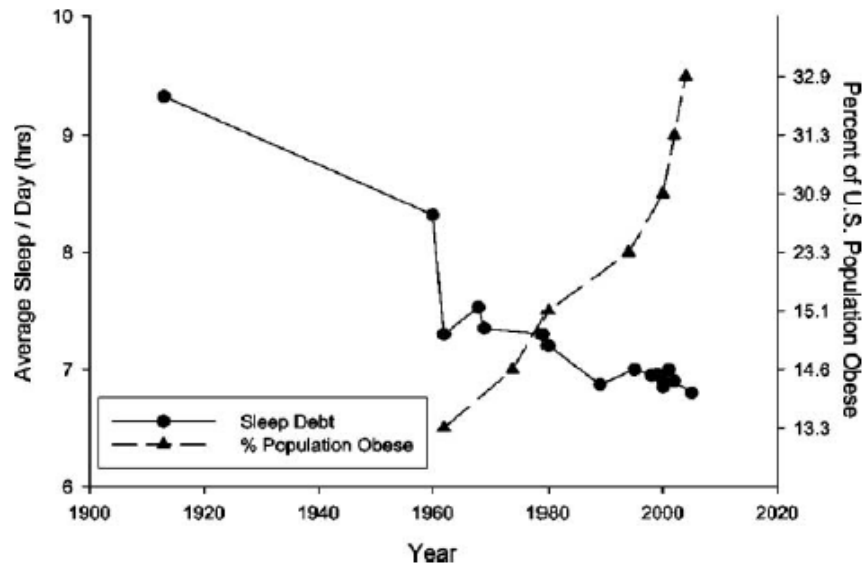


Figure 1. The relationship between fewer hours of sleep per day (sleep debt) and the incidence of obesity in adults from 1960 to the present (McAllister et al. 2009).

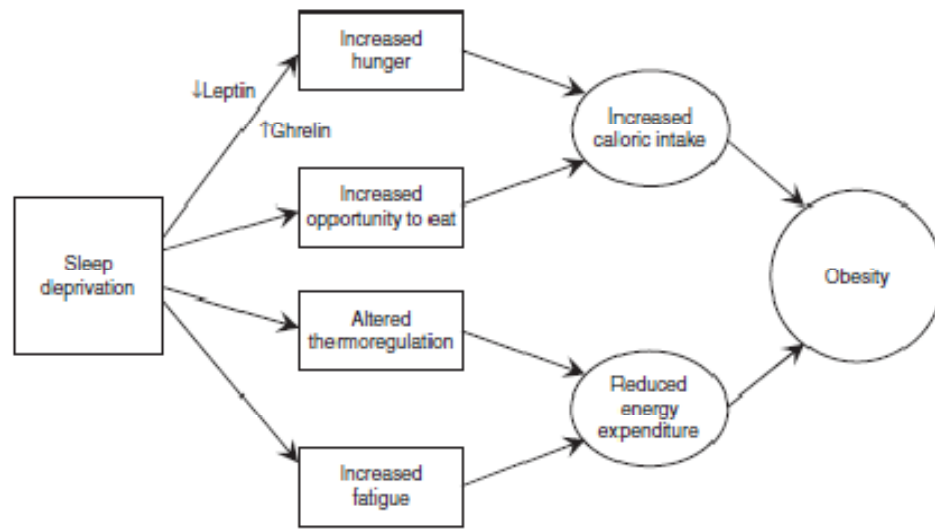


Figure 2. Potential mechanisms by which sleep duration may predispose obesity (Patel et al. 2008)

Table 1. Longitudinal studies of sleep duration (SD) and weight in children.

Author, country, year	Sample	Age	Sleep measure	Results
Carter, New Zealand, 2011	244	3-7	5 d waist accelerometry Actical	Children with lower sleep amounts are at increased risk for higher BMI.
Reilly, UK,2005	8,234	38 mon/ 7 yr	One question to parents	Not assessed/Short SD associated with ↑obesity risk.
Agras, USA,2004	150	3-5/ 9.5 yr	One question to parents each year over 3 years	Not assessed/Short SD associated with ↑ overweight risk. Short SD at ages 3–5 predicted overweight at age 9.5. At follow up, overweight children slept 30 min < than normal weight.
Snell, USA,2007	2,281	3-12/8-17	One weekday, one weekend time diary by parent or child	Negative linear at both time points Less sleep at time 1 correlated with overweight at time 2.
Dieu, Vietnam, 2007	670	6-7/7-8	Questionnaire	Negative linear.

*all studies measured BMI except as noted

Table 2: Longitudinal studies of sleep duration (SD) and weight in adults.

Hasler, Switzerland, 2004	496	27/40	Three questions at four time points	Baseline: Short SD associated with ↑ obesity risk. Longitudinal: Association weakened with ↑ age. *Reported BMI.
Gangwisch, USA, 2005	9,588	32-86/41- 95	One sleep question	Baseline: U-shaped association between SD and obesity risk with minimum at 7 h. Strongest cross-sectional association in the youngest tertile. Longitudinal: The relationship ↓ with age. Those having a shorter SD gained more weight than those having a longer SD.
Patel, USA, 2006	68,183	45-65/61- 81	One sleep question at baseline and every two years	U-shaped association between SD and obesity risk with minimum weight in those having a SD of 7 h. Longitudinally: small association between short SD and weight gain. *Reported BMI.
Bjorkelund, Sweden 2005	1,462	38-60	One sleep question	Baseline: SD was inversely correlated with both BMI and waist-to-hip ratio. None prospectively.

*all studies measured BMI except as noted

Table 3: Cross-Sectional studies sleep duration (SD) and weight in children

Author, country, year	Sample	Age	Sleep measure	Results
Locard, France, 1992	1,031	5	One question to parents	Short SD associated with ↑ obesity risk.
Von Kries, Germany, 2002	6,862	5 - 6	One question to parents	Short SD associated with ↑ obesity risk.
Sekine, Japan, 2002	8,274	6 - 7	One question to parents	Short SD associated with ↑ obesity risk. Higher risk in boys.
Knutson, USA, 2005	4,486	17	One question to child	Short SD associated with ↑ overweight risk in boys only.
Padez, Portugal, 2005	4,511	7 - 9	Weekday/ weekend questions to parents	Short SD associated with ↑ obesity risk.
Chaput, Canada, 2006	422	5 - 10	One question to parents	Short SD associated with ↑ obesity risk.
Chen, Taiwan, 2006	656	13 - 18	One question to child	Low frequency of at least 6-8h on weekdays associated with ↑ obesity risk.
Eisenmann, Australia, 2006	6,324	7-15	Questions to child	Negative linear.
Knutson, USA, 2007b	1,546	10-19	24h time diary, self reported	N shape.
Nixon, New Zealand, 2007	519	7	24h waist actigraphy, MTI	Short SD associated with overweight and obesity.
Gupta, USA, 2002	383	11 - 16	24 h actigraphy, Motionlogger	Short SD associated with ↑ obesity risk.

Table 4. Cross-sectional studies of sleep duration (SD) and weight in Adults

Author, country, year	Sample	Age	Sleep measure	Results
Gortmaker, USA, 1990	712	-	One sleep question	No association. *Reported BMI.
Vioque, Spain, 2000	1,772	≥15	One sleep question	Short SD associated with ↑obesity risk.
Shigeta, Japan, 2001	453	53	One sleep question	Short SD associated with ↑ obesity risk.
Heslop, UK, 2002	6,797	35-64	One sleep question	Short SD associated with ↑ obesity risk.
Kripke, USA, 2002	1,116,936	33- 102	One sleep question	U-shaped association between SD and BMI among women with the minimum BMI at 7 h. Monotonic trend in men with > SD associated with a lower BMI.
Tamakoshi, Japan, 2004	104,010	40-79	One sleep question	Short SD associated with lower BMI. *Reported BMI.
Amagai, Japan, 2004	11,325	19-93	Bedtime/wake- time questions	No association between SD and BMI.
Cournot, France, 2004	3,127	32-62	Bedtime/wake- time questions	Short SD associated with higher BMI in women but not in men.
Ohayon, Europe, 2004	8,091	55- 101	Nighttime/daytime sleep questions	No association between short SD and BMI but positive association between long SD and underweight. *Reported BMI.
Taheri, USA, 2004	1,024	53	6-Day sleep diary	U-shaped association between SD and BMI with minimum BMI at 7.7h.
Ohayon, France, 2005	1,026	≥60	Nighttime/ daytime sleep questions	Short SD associated with higher BMI. Obese were more likely to report daytime naps resulting in no association.
Singh, USA, 2005	3,158	18 - 65	Weekday/ Weekend sleep questions	Short SD associated with higher obesity risk with minimum risk associated with a SD of 8–9 h. *Reported BMI.

Vorona, USA, 2005	924	18 - 91	Weekday/ Weekend sleep questions	Short SD associated with higher BMI.
Gottlieb, USA, 2006	5,910	40-100	Weekday/ Weekend sleep questions	U-shaped association between SD and weight with minimum at 7–8 h.
Kohatsu, USA, 2006	990	48	One sleep question	Short SD associated with higher BMI.
Moreno, Brazil, 2006	4,878	40	One sleep question	SD <8 h per day was associated with higher odds of obesity.
Chatput, Canada, 2007	740	21-64	One sleep question	U-shaped association between SD and obesity risk with minimum at 7-8h.
Ko, China, 2007	4,793	17 - 83	One sleep question	Short SD associated with higher BMI and waist circumference. Negative linear association for men, no association for women.
Gottlieb, USA, 2005	1,486	53 - 93	Sleep questionnaire	No association.
Bjorvatn, Norway, 2007	8,860	40–45	Sleep questionnaire	U-shaped.
Wolff, Germany, 2008	2,383	20–79	Two sleep questions	Slight irregular U-shape.
Hasler, Switzerland, 2004	367	40	Three sleep questions	No association at age 40. Negative linear cross–sectional associations when participants were younger.
Lauderdale, USA, 2006	669	35-49	72h Actigraphy, Actiwatch	Weak inverse correlation between SD and BMI - not statistically significant. Sleep was assessed 3 years after BMI.

Sleep Duration (SD)

*All studies measured BMI except as noted.

Table 5. BOD POD® percent body fat equations.

Name	Equation	Population
Siri, 1961	$\% \text{ fat} = (4.95/D_b - 4.50) * 100$	General Population
Schutte et al. 1984	$\% \text{ fat} = (4.374/D_b - 3.928) * 100$	African American and Black Males
Ortiz et al. 1992	$\% \text{ fat} = (4.83/D_b - 4.37) * 100$	African American and Black Females
Brozek et al. 1963	$\% \text{ fat} = (4.57/D_b - 4.142) * 100$	Lean and obese individuals
Wagner and Heyward, 2001	$\% \text{ fat} = (4.858/D_b - 4.394) * 100$	African American and Black males
Lohman, 1986	$\% \text{ fat} = (C1/D_b - C2) * 100$	Children 17 and under

**C1 and C2 are constants based on age and sex

CHAPTER III: SUBJECTIVE AND OBJECTIVE METHODS TO EXAMINE SLEEP IN CHILDREN AND ADULTS

Shiny Parsai, Randal Foster and Lorraine Lanningham-Foster, PhD

Department of Food Science and Nutrition, Iowa State University, USA

A paper to be submitted to the *International Journal of Obesity*

Abstract

Background: The increasing rates of obesity and the prevalence of sleep deprivation in the modern environment may be linked. The objective of this study was to use two novel objective tools to study sleep in children and adults. **Methods:** The study included 43 individuals from 18 families (10 men, 17 women, 11 boys, and 5 girls). Subjects participated in a week-long study to monitor their sleep using an accelerometer and a pattern-recognition system (MSR145 and the SenseWear WMS® Mini armband, respectively) and sleep logs. BMI was calculated using height and weight. **Results:** No difference was observed between children's daily self-reported sleep log and parental reported weekly sleep log for the child. Both of the objective tools estimated similar sleep duration data from the subjects when compared with self-report of sleep. The MSRR accelerometer had a slightly better correlation than SenseWear pattern-recognition system when compared with a subjective daily reported sleep log (0.399 vs. 0.1785, respectively). Sleep duration was inversely correlated with age for all measurement tools. **Conclusions:** Objective tools showed similar sleep amounts for the participants when compared with the sleep log, but the objective tools over-estimated sleep amounts

compared to the sleep log for shorter sleep hours and under-estimated for longer sleep hours.

Introduction

Obesity continues to be a serious epidemic. In 2009, 36.2% of the US population was overweight and 27.2% was obese¹. According to NHANES data, obesity has more than tripled for children 5 to 16% when comparing the survey periods 1971 to 1974 and 2007 to 2008². The growing rates of obesity make it vital to look beyond diet and physical activity and to study other potential causes of obesity such as sleep. Post World War I there has been an inverse relationship between lower sleep duration and degree of obesity³. Several cross-sectional and longitudinal studies that have found similar relationships in children and adults, although the relationship appears to be greater in children compared to adults^{4,5,6,7}. Strongest cross-sectional associations have been found in the younger children. Longitudinal studies show that the relationship decreases with age and individuals with a shorter sleep duration gained more weight than those having a longer sleep duration⁸. Considering that the sleep and obesity link appears to be stronger in children, examining sleep using accurate sleep assessment tools is essential.

Several mechanisms have been proposed that link sleep deprivation to obesity through endocrine, metabolic or neurologic pathways. For example, sleep deprivation may lead to increased caloric intake via increased hunger through increasing ghrelin and decreasing leptin amounts^{9,10}. Also, less sleep provides an increased opportunity to eat. Sleep deprivation may also cause decreased energy expenditure through altered thermoregulation and increased fatigue¹¹. The causal relationship between sleep and

obesity is difficult to sort out as sleep disorders could contribute to sleep deprivation and increased obesity, or obesity related health problems may cause difficulty in sleeping.

In order to examine the mechanism between sleep and obesity, a variety of assessment tools have been employed^{6,12,13,14}. There are several subjective and objective tools for measuring sleep. Subjective tools include sleep logs, diaries, questionnaires, and sleep quality measures. In using subjective assessment tools, there is a trade-off between quantity and quality of data collected due to subject burden, as more detailed sleep logs could provide more information but take longer for the subjects to complete¹⁵. Objective tools include polysomnography (PSG), actigraphy, pattern-recognition systems and accelerometers. Using accelerometers to study sleep as well as physical activity allows for faster data collection in free-living persons while minimizing cost and participant burden¹⁶. Each method has various strengths and weaknesses which must be carefully weighed in order to more accurately study the relationship between sleep and other health issues. In the present study we assessed sleep by comparing the MSR accelerometer and SenseWear pattern recognition monitor to a sleep log. Our hypothesis was that the tools would report similar sleep durations as compared to subjective sleep logs. We also hypothesized that sleep duration would decrease with age.

Methods

Research Participants: This study was approved by the Institutional Review Board (IRB) at a large mid-west University. Participants were recruited through university faculty and staff email lists. Flyers were also posted on the campus and in the

community. Inclusion criteria included families living in the same household with children greater than 7 years of age. A minimum of one parent and one child were required per family to be eligible to participate. Couples living in the same household were also eligible to participate. Exclusion criteria included smokers, pregnant females, participants unable to stand, or those who could not participate due to physical or mental defect. Any adult unable to give informed written consent was excluded. Participants were excluded if they had a diagnosed sleep disorder such as insomnia or sleep apnea. Individuals who agreed to participate signed the informed consent documents. For children 18 years old and younger, informed written consent was obtained from the parent or guardian and informed written assent was obtained from the minor.

Study Procedures: Following the email and flyer notice, individuals who expressed interest in study participation were provided more information and the exclusion criteria. Subjects who were still interested in participating and met the criteria were scheduled for a screening visit. The entire study including screening, body composition assessment, and one week of sleep assessment lasted 9 days for each family member. During the first visit, the procedures were explained and signatures on consent and assent forms were obtained. Individuals were also asked to complete a quick five question screening survey concerning tonsils, adenoids, sleep quality, sleep disorders, and restless leg syndrome. Following this, the individual's weight (nearest 0.1 kg) and height (nearest 0.1 cm) were obtained with the participant's shoes removed using a scale and stadiometer (Seca Model 763, Sec GmbH, Hamburg, Germany). Body mass index (BMI) was calculated using weight in kilograms divided by the square of height in meters.

At the second visit, body composition was assessed using air displacement plethysmography (BOD POD®, models 2000A and 2007A, Cosmed USA, Concord, CA) according to the manufacturer's instructions. Subjects were asked to refrain from consuming any food or beverage including water and refrain from exercise 2 hours before the test. Subjects were informed prior to the testing about clothing constraints which included no padding, jewelry, glasses, or underwires. During the measurement, participants wore form-fitting clothing and a swim cap. The BOD POD® measures body volume through air displacement with a calculated lung volume and body mass with a calculated scale. Body density is computed (mass/volume) and this density is used by separate equations were used to predict body composition in adults ≥ 18 years or children ≤ 17 years^{17,18} (Software versions 1.69 and 4.5.2).

During the week of the sleep assessment, sleep was monitored with subjective (sleep logs) and objective (accelerometer and pattern-recognition system) measures. Participants wore close-fitting shorts that had MSR (MSR145, MSR Electronics GmbH, Zurich, Switzerland) accelerometers attached to both outside thighs using Velcro® straps mounted to the sensors. The shorts were worn underneath normal clothing and over undergarments. The SenseWear Mini Armband (Model: MF-SW, BodyMedia Inc., Pittsburgh, PA) pattern-recognition system was worn over the triceps of the left arm.

All participants filled out a daily sleep log and one parent also filled out a week-long sleep log for the child, at the end of the study. Participants did not wear the accelerometer or pattern-recognition system during showering, bathing, swimming, or during any other contact with water. The data from the MSR sensors was downloaded each day and a clean pair of shorts with new sensors was provided for the participants.

The subjects were able to continuously wear the SenseWear Mini armband for the entire week. The sleep logs and monitors were collected at the end of the week-long study.

Data Analysis: Sleep amounts were compared by determining the averaging the week's values of each sleep tool. This included the lapse between sleep and wake as determined by algorithmically guided manual analysis of accelerometry (MSR), proprietary sleep-determining algorithm (SenseWear Mini), the lapse between sleep and wake time as self-reported by the daily sleep log (Calculated Log), and the duration of sleep as self-reported in the daily sleep log. For the manual analysis of MSR accelerometry data, the same guidelines used with multiple sleep latency test (MSLT) were applied; MSLT records how fast individuals fall asleep with sleep latency of 10 to 15 minutes reflects mild sleepiness¹⁹. A cut-off of 10 minutes was used to define sleep for MSR. All modalities were compared to each other using regression and Bland-Altman analysis. The novel objective tools were compared to the traditional subjective sleep log. The data were examined using continuous (age) and categorical (adult/child) covariables. ANOVA and ANCOVA were used when appropriate to determine various covariable effects on sleep. Regression analyses were carried out when deemed appropriate. Post-hoc tests were used with ANOVA and ANCOVA with a Bonferroni correction applied to give an overall significance level of $P < 0.05$. For regressions, Pearson's correlation coefficient was used to assess goodness of fit and the F-test determines significance. Significance is assumed at $P < 0.05$. These statistical analyses were conducted using StatView v. 5.0 (SAS Institute, Cary, N.C.).

Results

A total of 45 children and adults agreed to participate in the study. The final group of participants included 10 men, 17 women, 11 boys, and 5 girls. Data ($n = 2$) were excluded due to non-compliance. The mean ages for men and women were 46 ± 7 years and 43 ± 9 years, respectively. All the participants in the study were Caucasian. Table 1 lists the demographics such as height, weight, BMI, BMI percentile, age, and average sleep duration estimated by each tool (mean \pm SD). Men had a mean BMI of $31 \pm 5.2 \text{ kg/m}^2$ and women had a mean BMI of $27 \pm 5.3 \text{ kg/m}^2$, but they were not significantly different. For adults, 9 were normal weight, 10 were overweight, and 10 were obese. Women and men also had similar amounts of body fat as assessed by the BOD POD®; $31 \pm 9.9 \%$ and $35 \pm 10.3 \%$, respectively. Most children had a normal weight and the mean BMI percentile was 61 ± 20.4 . Of the 16 children, 13 were normal weight, 2 were overweight, and 1 was obese. Girls and boys had similar percent body fat, $20 \pm 5.0 \%$ and $18 \pm 8.8 \%$, respectively. Sleep durations for each group and each measurement tool are also reported in Table 1.

A comparison of daily self-reported sleep amount of children with weekly estimate of children's sleep time from parents found that there was no difference between parental and self-report sleep times. For this reason, the self-reported values for children were used for further analyses. Boys and girls had similar self-reported daily sleep log sleep amount, $8.93 \pm 0.94 \text{ hrs}$ and $9.05 \pm 0.39 \text{ hrs}$, respectively. Men also reported similar sleep amounts compared to women, $7.03 \pm 1.04 \text{ hrs}$ and $7.19 \pm 0.83 \text{ hrs}$, respectively, and, there were no sex-related differences in sleep duration in children or adults.

Table 2 includes the regression equations comparing subjective and objective sleep tools in children and adults. Reported average daily sleep log amount was compared with SenseWear Mini, MSR left leg (MSRL), MSR right leg (MSRR), and calculated daily sleep log time. The strongest correlation was found between reported log and calculated log time, followed by MSRR, MSRL, and SenseWear Mini with $R^2 = 0.798, 0.399, 0.3629, 0.1785$, respectively. Figure 1 shows the comparison of the two objective sensors to a sleep log in children and adults. It was found that both objective measures tended to over-estimate for shorter sleep durations and under-estimate for longer sleep durations. Figure 2 shows Bland-Altman plots of objective systems compared to a sleep log in children and adults. No patterns were seen in comparing MSRL and MSRR with sleep log, but a slight over-reporting of sleep amount was seen when SenseWear Mini as compared to sleep log for shorter sleep durations.

We also compared sleep duration to age (Figure 3). Self reported log sleep duration decreased with age ($P < 0.0001$). The steepest slope was seen with the sleep log-reported sleep duration and age and the smallest steep slope was seen with the SenseWear-reported sleep duration and age. The correlations when comparing sleep duration and age using sleep log, MSRL, MSRR, SenseWear were 0.54 , 0.09, 0.09, and 0.15, respectively.

Discussion

This study was designed to compare objective (SenseWear Mini armband and MSR) and subjective (sleep log) sleep assessment tools in measuring sleep in children and adults. The study was also designed to explore a possible relationship between sleep

amounts and age. We hypothesized that the novel sleep assessment tools would estimate similar sleep amounts as compared to a subjective sleep log.

Both of the objective tools captured similar sleep amount data from the subjects when compared to the subjective sleep log. The objective monitors over-estimated as sleep amount decreased and under-reported as sleep amount increased, relative to the sleep logs. The MSR had a slightly better correlation than SenseWear Mini when compared with subjective daily reported sleep log. The Bland-Altman plots showed that SenseWear Mini over-estimated sleep as sleep hours decreased. There was a random distribution when comparing the objective tools to the sleep log.

It was evident that children slept more than adults, regardless of the sleep measurement used. This observation matches the National Sleep Foundation guidelines which recommend that children need more sleep compared to adults. The National Sleep Foundation recommends that children between the ages of 5 and 10 should sleep 10 to 11 hours a night, teens ages 10 to 17 need to sleep between 8.5 and 9.25 hours whereas adults should sleep 7 to 9 hours a night²⁰. Considering correlations, the measure that showed the strongest relationship between sleep and age was the self-recorded sleep log, followed by SenseWear, and MSR.

Cross-sectional, cohort, and prospective studies in children reveal that short sleep duration is strongly associated with obesity. In a survey of 4,486 American children with mean age of 16.6 years, it was found that short sleep duration predicted higher BMI z-score in boys but no relationship was found in girls⁶. The prospective longitudinal studies have found that short sleep duration was associated with increased BMI^{21,22}, being overweight⁷ and increased obesity risk^{23,24}. All of these studies assessed sleep using

subjective measures. Sleep duration studies in children on sleep have relied on parental report of children's average sleep amount. In the present study, children's daily self-recorded sleep duration was not different compared to parental-reported sleep duration for the child.

Few studies have measured sleep objectively in children. Gupta et al. (ref. 13) measured sleep duration with wrist actigraphy over a 24-hour period children aged 11–16 and found that the odds of obesity increased 5-fold for every hour reduction in sleep duration. Benefice et al. (ref. 25) assessed sleep duration using an uniaxial CSA (Computer Science and Applications Inc., Shalimar, FL, USA) model 7164 accelerometer worn near the hip to assess sleep over 3–4 days in girls aged 13–14 years. Every 6.85 minute reduction in sleep increased BMI by 1 kg/m². Studies suggest that boys may be more susceptible to sleep loss than girls because there is a stronger association between less sleep and obesity in males. It was found that the OR for obesity associated with sleep duration of 10 or fewer hours compared to 12 or more hours was 5.7 in boys and 3.2 in girls⁴. Also, it was found that each hour reduction in sleep duration increased the risk of being overweight by 10% in boys, but no significant effect was found in girls⁶. In our study we did not see any significant relationship between sex, sleep duration and obesity in children. For children, it was difficult to determine if there was a relationship with obesity and sleep duration due to the small number of overweight and obese children recruited in families.

The strong correlation between sleep debt and obesity is also found in some adult studies, but overall the data is less consistent for adults. Studies have found no association, a U-shaped relationship, a relationship in only one sex, and one study found

short sleep duration was associated with reduced weight. An adult longitudinal study found a positive relationship between sleep duration and future weight, though this relationship decreased with age⁸. The mixed findings in adult studies may be due to a more complex relationship between sleep duration and weight in this age group. The more negative finding in adults suggests that the relationship between sleep duration and weight may weaken with age.

Some limitations to our study are that we were not able to recruit many families with children from a wide range of body weight classifications. A majority of the children were normal weight according to their BMI percentile. Most families consisted of one parent and child or couples. This limited the number of children that participated in the study and hence very few overweight and obese children participated to adequately study the relationship between sleep amount and weight for children. There were however, a larger number of adults with a good distribution of normal weight, overweight and obese individuals, allowing us to make comparisons between BMI categories in adults. Another limitation of the study is that the tools were not compared to polysomnography which is not feasible to do in free-living subjects.

In conclusion, it was seen that the objective tools showed similar sleep amounts for the participants, but under-estimated compared to the sleep log as sleep amount decreased and over-estimated as sleep amounts increased. Sleep duration was inversely correlated with age. Future studies targeting children and adults to study sleep and obesity using these objective tools would be beneficial. It is also possible that the relationship between sleep duration and obesity may be explored in existing data sets

where these objective measurement tools have been employed for other purposes such as physical activity assessment.

Tables and Figures

TABLE 1: Demographic characteristics of all study participants by age and sex categories (adult/child, male/female) and self-reported sleep duration. All data are listed as are mean \pm Standard Deviation.

N = 43	Men (n = 10)	Women (n= 17)	*Boys (n =11)	*Girls (n = 5)
Height (cm)	179.55 \pm 9.43	164.29 \pm 7.61	160.1 \pm 17.05	152.86 \pm 10.38
Weight (kg)	101.22 \pm 20.05	73.24 \pm 16.29	57.15 \pm 20.69	42.06 \pm 7.36
BMI (kg/m²)	31.33 \pm 5.20	27.08 \pm 5.33	21.5 \pm 4.02	17.86 \pm 0.92
BMI percentile	--	--	69.45 \pm 19.20	44.8 \pm 10.44
Body Fat%	31.2 \pm 9.94 ^a	35.53 \pm 10.32 ^b	18.47 \pm 8.77 ^c	20.37 \pm 5.03 ^d
Age (yrs)	46 \pm 7.49	43.35 \pm 9.08	13.72 \pm 3.74	11.8 \pm 1.78
Avg SD				
*Sleep Log Rep	7.03 \pm 1.04	7.19 \pm 0.83	8.93 \pm 0.94	9.05 \pm 0.39
*Sleep Log Calc	7.28 \pm 0.90	7.94 \pm 0.83	9.09 \pm 1.02	9.19 \pm 0.47
SenseWear	7.14 \pm 0.62	7.61 \pm 0.74	7.82 \pm 0.77	8.44 \pm 0.33
MSRL	7.79 \pm 1.11	8.36 \pm 1.38	8.77 \pm 1.10	8.85 \pm 0.80
MSRR	7.64 \pm 1.42	8.33 \pm 1.26	8.61 \pm 1.06	8.72 \pm 0.73

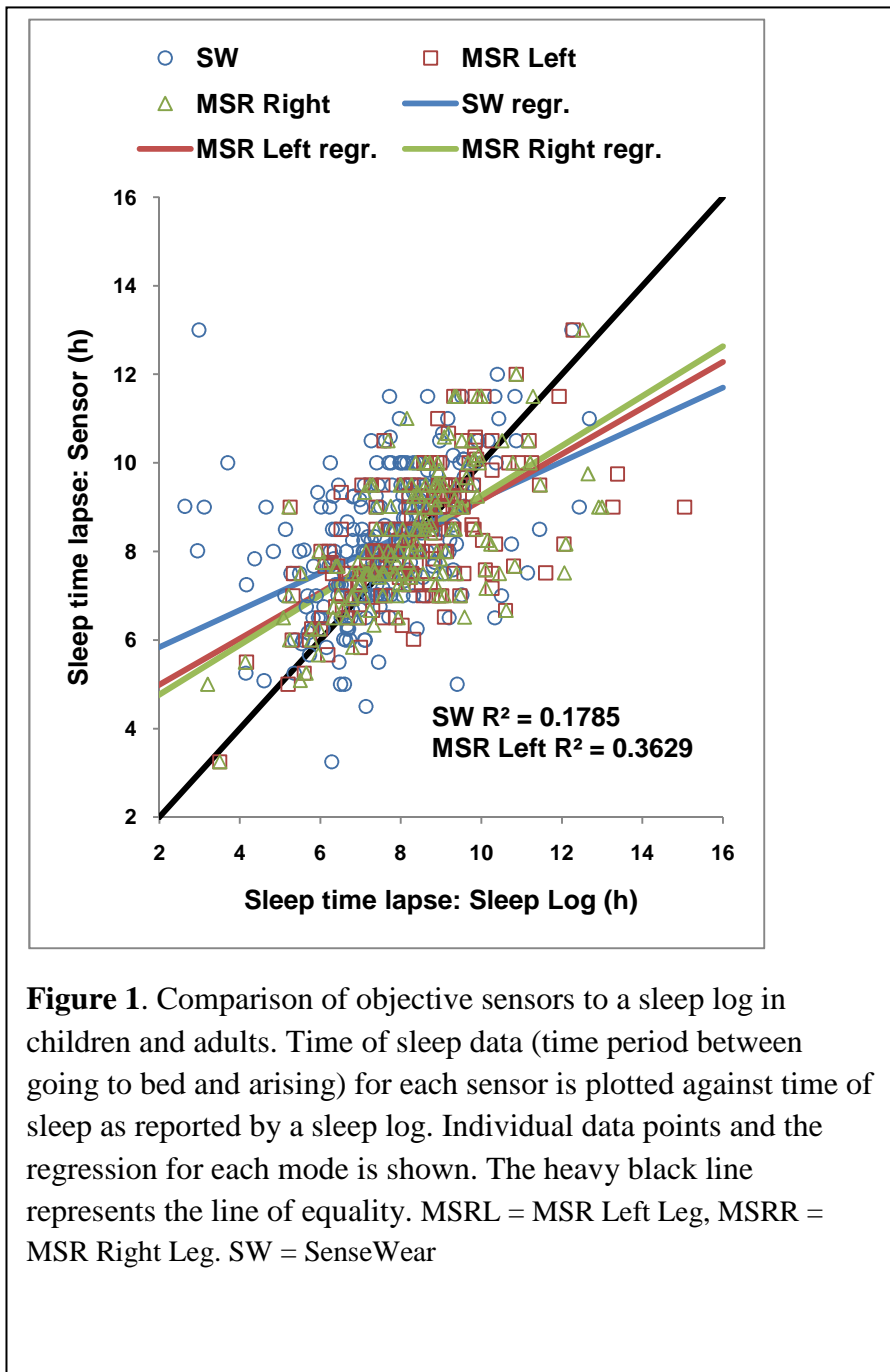
*Age of boys and girls was \leq 18 years old. a-d is BOD POD body fat% from a smaller sample men (n=4), women (n=13), boys (n=8), and girls (n=3). SD = Sleep duration. *Sleep Log Rep = amount of sleep reported for sleep duration on sleep log, Sleep Log Calc = amount of sleep calculated from sleep log bed time and wake time.

Table 2: Regression equations comparing subjective and objective sleep assessment tools.

	r²	slope	Intercept
RepLog vs SW	0.1785	0.4107	5.01
RepLog vs MSRL	0.3629	0.521	3.95
RepLog vs MSRR	0.399	0.562	3.61
RepLog vs CalcLog	0.798	0.853	1.53

RepLog = Reported Log, CalcLog = Calculated Log, MSRL = MSR Left Leg, MSRR = MSR Right Leg.

Reported log is the daily sleep log time recorded to the question “Total amount of time you slept.” CalcLog is the lapse between sleep log questions “Time you went to bed last night” from “Time you started your day.”



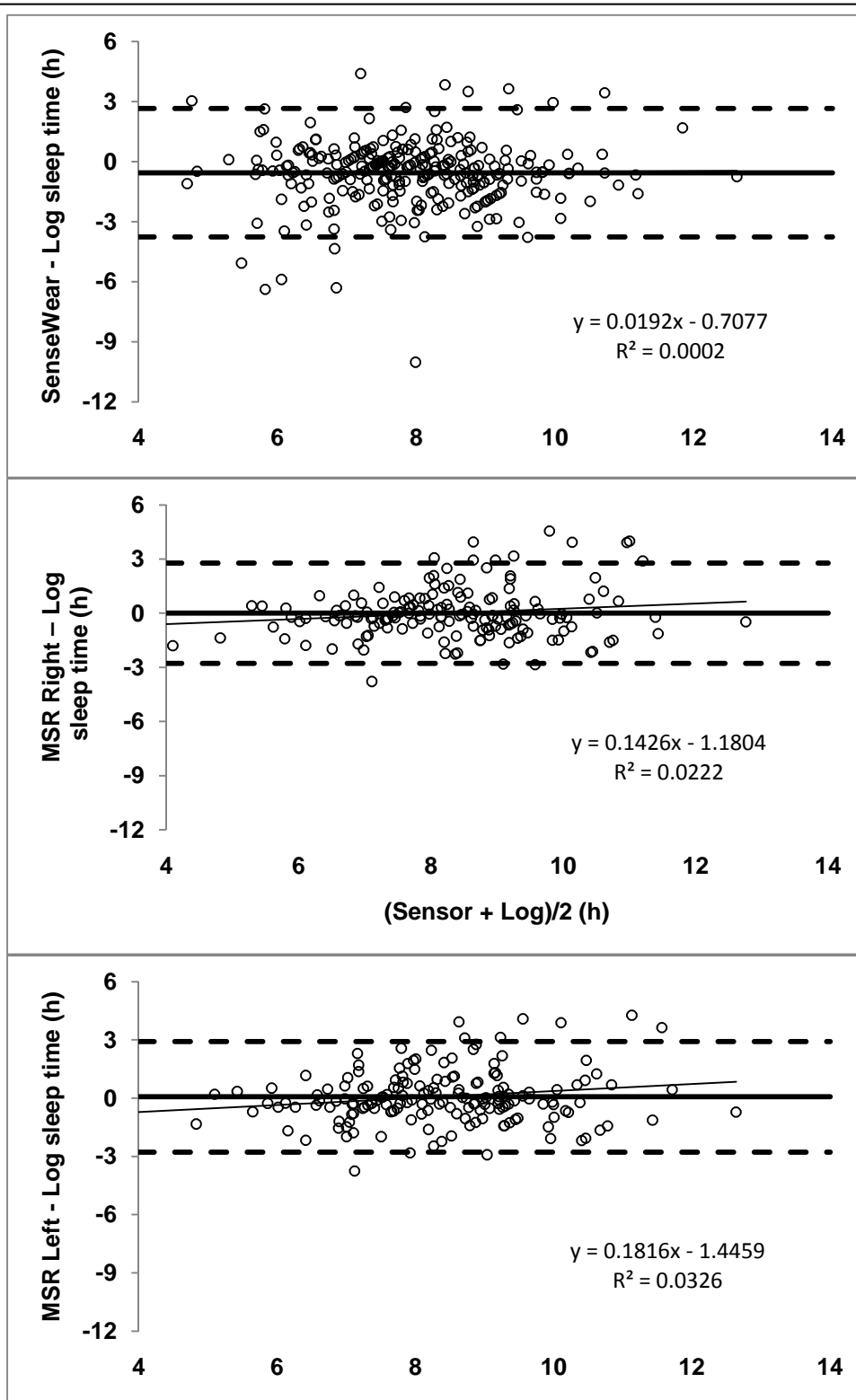


Figure 2: Bland-Altman plots: objective systems compared to a sleep log in children and adults. The sensor - log is plotted against the average of the sleep log and the sensor for each mode. The solid line represents the mean residual and the dashed lines represent ± 2 S.D. of the residuals. MSRL = MSR Left Leg, MSRR = MSR Right Leg.

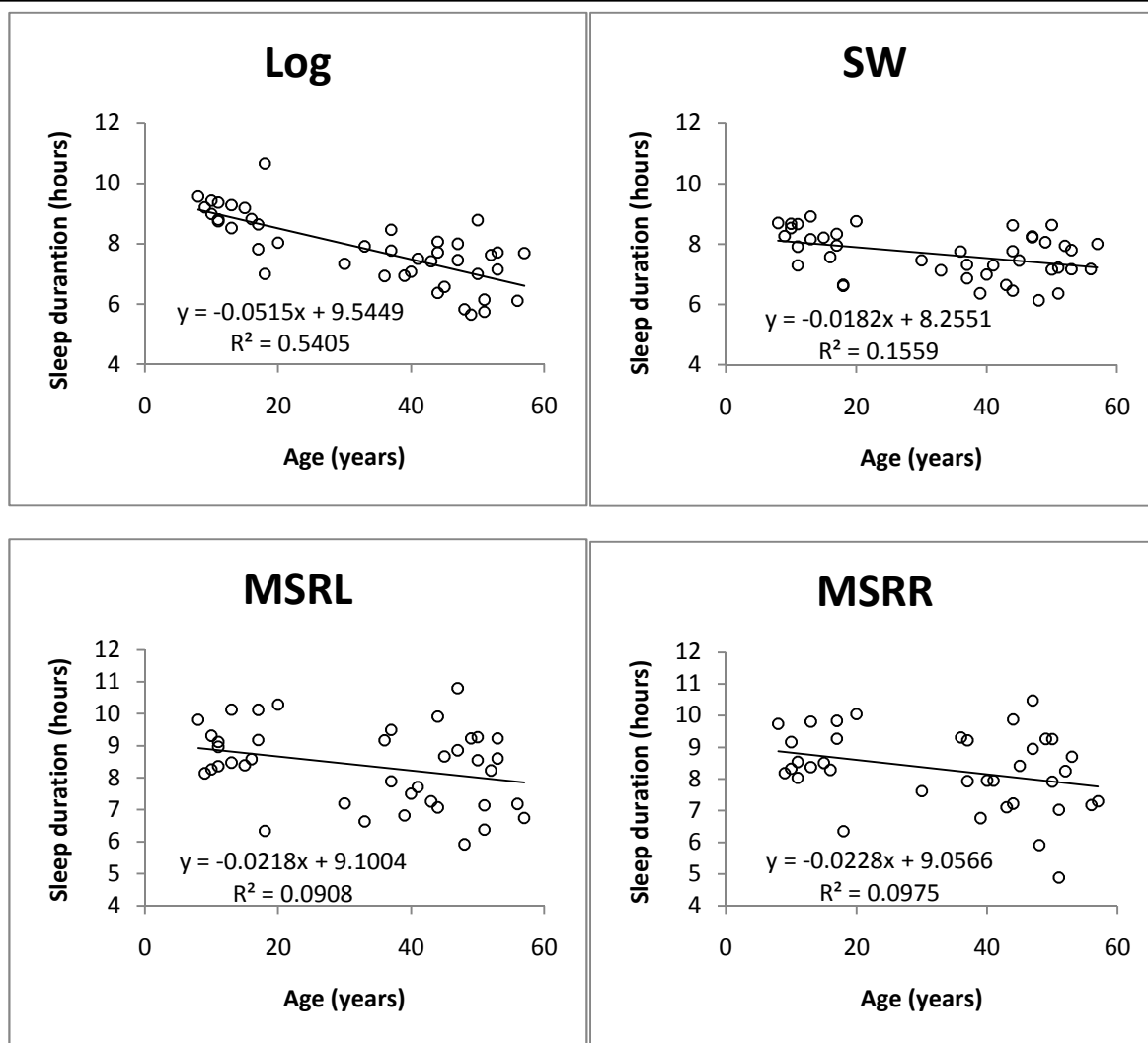


Figure 3. Sleep duration compared to age in children and adults. Sleep duration was determined by a sleep log for a one week period. Sleep duration was plotted against the age of each participant. MSRL = MSR Left Leg, MSRR = MSR Right Leg. SW = SenseWear.

References

1. Behavioral Risk Factor Surveillance System. Prevalence and Trends Data: Overweight and Obesity (BMI) – 2009. Available from <http://apps.nccd.cdc.gov/brfss/list.asp?cat=OB&yr=2009&qkey=4409&state=All> (cited June 15, 2011).
2. Ogden CL, Carroll MD. Prevalence of Obesity Among Children and Adolescents: United States, Trends 1963–1965 Through 2007–2008. Available from http://www.cdc.gov/nchs/data/hestat/obesity_child_07_08/obesity_child_07_08.pdf (cited June 10).
3. McAllister EJ, Dhurandhar NV, Keith SW, Aronne LJ, Barger J, Baskin M, Benca RM *et al.* Ten putative contributors to the obesity epidemic. *Critical Reviews in Food Science and Nutrition*. 2009; **49**: 868–913.
4. Chaput JP, Brunet M, Tremblay A. Relationship between short sleeping hours and childhood overweight/obesity: results from the ‘Quebec en Forme’ Project. *International Journal of Obesity*. 2006; **30**: 1080–5.
5. Padez C, Mourao I, Moreira P, Rosado V. Prevalence and risk factors for overweight and obesity in Portuguese children. *Acta Paediatrica*. 2005; **94**: 1550–7.
6. Knutson KL. Sex differences in the association between sleep and body mass index in adolescents. *The Journal of Pediatrics*. 2005; **147**: 830–4.
7. Agras WS, Hammer LD, McNicholas F, Kraemer HC. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *Journal of Pediatrics*. 2004; **145**: 20–5.
8. Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. *Sleep*. 2005; **28**: 1289–1296.
9. Taheri, S., Lin, L., Austin, D., Young, T. and Mignot, E. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. *PLoS Medicine*. 2004; **1**: e62.
10. Chaput JP, Després JP, Bouchard C, Tremblay A. Short sleep duration is associated with reduced leptin levels and increased adiposity: results from the Québec Family Study. *Obesity*. 2007; **15**: 253–61.
11. Patel SR and Hu FB. Short Sleep Duration and Weight Gain: A Systematic Review. *Obesity*. 2008; **16**: 643–53.
12. Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR. Mortality associated with sleep duration and insomnia. *Archives of General Psychiatry*. 2002; **59**: 131–136.

13. Gupta NK, Mueller WH, Chan W, Meininger JC. Is obesity associated with poor sleep quality in adolescents? *American Journal of Human Biology*. 2002; **14**: 762–768.
14. Taheri S. Sleep and metabolism: bringing pieces of the jigsaw together. *Sleep Medicine Reviews*. 2007; **11**: 159–162.
15. Iwasaki M, Iemura A, Oyama T, Matsuishi T. A novel subjective sleep assessment tool for healthy elementary school children in Japan. *Journal of Epidemiology*. 2010; **20**: S476–81.
16. Weiss AR, Johnson NL, Berger NA, Redline S. Validity of activity-based devices to estimate sleep. *Journal of Clinical Sleep Medicine*. 2010 Aug 15; **6**: 336–42.
17. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. *Nutrition*. 1993; **9**: 480–91.
18. Lohman, TG. Assessment of body composition in children. *Pediatric Exercise Science*. 1986; **1**: 19–30.
19. Teofilo LC. *Sleep Medicine: Essentials and Review*. 1st edition. USA: Oxford University Press; 2008.
20. National Sleep Foundation. How much sleep do we really need? Available from <http://www.sleepfoundation.org/article/how-sleep-works/how-much-sleep-do-we-really-need> (cited 2011 March 7).
21. Snell EK, Adam EK, Duncan GJ. Sleep and the body mass index and overweight status of children and adolescents. *Child Development*. 2007; **78**: 309–323.
22. Dieu HT, Dibley MJ, Sibbritt D, Hanh TT. Prevalence of overweight and obesity in preschool children and associated socio-demographic factors in Ho Chi Minh City, Vietnam. *International Journal of Pediatric Obesity*. 2007; **2**: 40–50.
23. Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I, Steer C, Sheriff A. Early life risk factors for obesity in childhood: cohort study. *British Medical Association (Clinical Research Edition)*. 2005; **330**: 1357.
24. Carter PJ, Taylor BJ, Williams SM, Taylor RW. Longitudinal analysis of sleep in relation to BMI and body fat in children: the FLAME study. *British Medical Association*. 2011; **26**: 342:d2712.
25. Benefice E, Garnier D, Ndiaye G. Nutritional status, growth and sleep habits among Senegalese adolescent girls. *European Journal of Clinical Nutrition*. 2004; **58**: 292–301.

CHAPTER IV: AN OBJECTIVE MEASUREMENT OF SLEEP ACROSS THE LIFE CYCLE IN FEMALES.

Shiny Parsai, Katie Smith, Randal Foster, Megan Barnes, Samantha Kling, Christina Campbell, and Lorraine Lanningham-Foster

Department of Food Science and Nutrition, Iowa State University, USA

A paper to be submitted to the journal *Obesity*

Abstract

Background: Today's modern environment requires women to increasingly do more on less sleep. The objective of the study was to study the relationship between sleep and body weight across the lifecycle of females and to compare sleep amounts in pregnant versus non-pregnant women. ***Methods:*** The study included a compilation of data from four studies which included a total of 56 females. This consisted of 14 pediatric girls, 11 young adults, 10 premenopausal, 9 pregnant women at week 18 of gestation, 9 pregnant women at week 35 of gestation, and 10 perimenopausal. In all studies, the subjects wore the SenseWear Mini pattern recognition system which estimated sleep duration and physical activity. Height and weight were measured to determine body mass index or BMI. ***Results:*** Results showed that on weekdays pregnant women on average slept 58 minutes longer than non-pregnant young adult and premenopausal women. Significant differences were seen between pregnant women at week 18 of gestation compared to premenopausal and young adult females for weekday sleep 7.42 ± 1.47 , 6.36 ± 0.71 , 6.26 ± 1.12 hours, respectively. Differences between

pregnant women at week 35 of gestation and young adult females were also seen for weekday sleep 7.21 ± 1.18 and 6.26 ± 1.24 , respectively. No significant differences were noted when considering total 7 day sleep duration, weekend sleep duration, and napping separately. Sleep efficiency comparisons estimated similar amounts. ***Conclusions:*** Pregnant women slept more than non-pregnant females in other age categories though more research is needed, in addition to sleep efficiency, to understand the quality of that sleep.

Introduction

Sleep is influenced by a variety of factors including age, sex, food, and physical and psychological health¹. Sleep loss is becoming prevalent in today's society due to technology use, environment, diet, medications, health conditions, smoking, shift work, and caffeine and alcohol consumption. Effects of sleep deprivation include a decrease in ability to hold attention, retain information, and reaction time². Less than 6 or 7 hrs a night has been associated with higher mortality rates³. Ferrie et al. (ref. 4) found that higher rates of all-cause mortality among participants who reported short sleep (≤ 5 hours) or long sleep (≥ 9 hours). The wide range of health and cognitive issues due to sleep loss, make it important to get an adequate night's sleep daily. Another consequence of sleep deprivation may be increased obesity rates. In women, Patel et al. (ref. 5) reported that in 68,000 U.S. nurses followed over a 16 year period, those sleeping 5 and 6 hours a night gained significantly more weight than did those getting 7 to 9 hours of sleep per night. Kripke et al. (ref. 3) found a U-shaped association between sleep deprivation and body mass index (BMI) among women with the minimum at 7 h. Despite increasing evidence

linking sleep deprivation and obesity, Marshall et al. (ref. 6) found that the evidence is not yet strong enough to give public health advice on sleep duration to be used as a modifiable risk factor for obesity. Additionally, there is no data showing that change in sleep duration results in weight loss. Further information is needed to better understand the relationship between sleep and obesity, particularly in women where obesity rates are higher^{3, 9, 8, 10}.

Sleep across the life cycle of women could be influenced by different reproductive stages. Sleep in women can also be affected by the phase of the menstrual cycle. The International Classification of Sleep Disorders includes several menstrual cycle related sleep disorders such as premenstrual insomnia, premenstrual hypersomnia, and menopausal insomnia. Menstrual cycle issues that can influence sleep include PMS and dysmenorrhea. Sleep during pregnancy could be affected by the rise in gonadal steroid hormones during the first trimester and the additional physical discomfort due to the growing fetus during the second and third trimesters. The rising hormone levels in the pregnant women have a soporific effect¹¹. Subjective studies found that during the first trimester pregnancy, women complain of nausea and vomiting, urinary frequency, backaches, and feeling uncomfortable and fatigued. During the second and third trimesters, complaints are related to fetal movements, heartburn, cramps or tingling in the legs, and shortness of breath¹². The enlarging fetus can press on the diaphragm resulting in shortness of breath; few studies exist on studying sleep and respiration during pregnancy¹³. Subjective and objective studies have found that that early on in pregnancy most women become sleepier, and their night-time sleep may become more disrupted¹¹.

Besides pregnancy, another reproductive stage that could influence sleep is menopause which is associated with hot flashes and night sweats¹⁴.

The 2007 National Sleep Foundation telephone poll focused on sleep and women in 1,003 American women between the ages of 18-64 to investigate women's sleep during different reproductive stages. The poll also studied how women's multiple roles affect their sleep and how often women experience sleep problems. It was found that 60% get a good night's sleep a few days a week or less. The percent of women who experienced sleep problems at least a few nights each week was 67% of which nearly half experienced sleep problems every night. Working mothers were more likely to experience sleep problems. A poor night's sleep lead to daytime sleepiness which caused women to experience high stress (80%) and to spend less time with family and friends (39%). Women of childbearing age experienced insomnia a few days a week and one third said their sleep cycle is disturbed during the week of their menstrual cycle. Most pregnant women said they experienced insomnia a few nights a week and about one third said they rarely or never get a good night's sleep. Rates of insomnia remained the same in the post-partum period. Decreasing amounts of time in bed reported were in the order of pregnant women, post-partum women, menstruating women, post menopausal women, and perimenopausal women¹⁵. A number of studies examining sleep duration and quality before, during, and after pregnancy have utilized subjective methods such as sleep logs, self-report, questionnaires, and Likert scales. There are limited studies on the use of objective tools to compare sleep in the pregnant and non-pregnant female population. In the present study, we used a recently developed (2004) accelerometer based pattern-recognition system used for assessing physical activity and sleep in females across the

life cycle. A comparison of the system to objective polysomnography¹⁶ and a recent comparison to sleep logs shows promise for the system in quantifying sleep (unpublished observation from our group). We hypothesized that pregnant females would have shorter sleep duration, especially at the later measurement period of 35 weeks gestation, compared to non-pregnant females due the added physical discomfort of pregnancy. Sleep duration was also compared to body weight across the life cycle.

Methods

Research Participants: Data were compiled from four studies focused on collecting sleep and/or physical activity information using the SenseWear Mini pattern-recognition monitor in families or females. Two of the studies were interventional studies which focused on physical activity and video gaming in young adults and families. Two studies were observational studies which focused on sleep amounts in families and physical activity in pregnant women. These studies were approved by the Institutional Review Board (IRB) at a large mid-west University. Participants were recruited through university faculty and staff email lists. Flyers were also posted on the campus and in the community. Inclusion criteria included families or females greater than 7 years of age. Exclusion criteria included smokers, participants unable to stand, or those who could not participate due to physical or mental defect. Any adult unable to give informed verbal consent was excluded. Individuals who agreed to participate signed the informed consent documents. An assent form was given to individuals 18 years old and younger and a parent or guardian provided informed written consent. With the inclusion

of data from all studies, there were a total of 14 girls, 31 non-pregnant women, and 11 pregnant women.

Study Procedures: Two data sets were part of larger observational studies and two data sets were part of larger intervention studies. For the intervention studies, baseline data were used. For each data set, height, weight, and sleep data were collected. Body weight was measured to the nearest 0.1 kg with shoes removed using digital scales (Seca Model 763, Sec GmbH, Hamburg, Germany, or Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO). Body height was measured to the nearest 0.1 cm with shoes removed using stadiometers (Seca Model 763, Sec GmbH, Hamburg, Germany, or Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, Quick Medical GS, Snoqualmie, WA). Body mass index (BMI) was calculated using height and weight measurements. One week of sleep and physical activity data were collected using the SenseWear Mini Armband (Model: MF-SW, BodyMedia Inc., Pittsburgh, PA) pattern-recognition monitor. On the first day of data collection, each participant was given the monitor to wear over the triceps of the left arm. Participants did not wear the pattern-recognition monitor during showering, bathing, swimming, or during any other contact with water. The subjects continuously wore the SenseWear Mini armband for the entire week. At the end of the measurement period, the monitors were returned to the study investigator.

Data Analysis

Sleep times were determined by averaging the week's values of a proprietary sleep-determining algorithm. The data was examined using continuous (age) and categorical (age grouping) covariables. Average sleep duration was as reported by the SenseWear Mini armband. Data were compared across 6 groupings of women, depending on age/pregnancy status. The data were analyzed using ANOVA with post-hoc t-testing with a Bonferroni correction to give an overall significant P-value of $P < 0.05$. These statistical analyses were conducted using StatView v. 5.0 (SAS Institute, Cary, N.C.). Sleep efficiency, reported in percent, was compared among the groups of females. The criteria for napping were set as any sleep longer than 10 minutes that was not part of a longer nighttime sleep.

Results

This study included 56 females from ages 8 to 57. The study included 14 pediatric females, 11 young adults, 10 premenopausal, 9 pregnant at week 18, and 9 pregnant at week 35, and 10 perimenopausal women. Using appropriate child or adult BMI classification (CDC), this included 28 normal weight, 16 overweight, and 12 obese females. For pregnant women, BMI classification was with pre-pregnancy height and weight information. Table 1 lists the demographics of all females by various age categories: pediatric, young adult, premenopause, pregnant at week 18, pregnant at week 35, and perimenopause, with average BMI of $17.24 \pm 1.43 \text{ kg/m}^2$, $29.82 \pm 3.56 \text{ kg/m}^2$, $29.22 \pm 7.48 \text{ kg/m}^2$, $29.22 \pm 7.48 \text{ kg/m}^2$, $28.87 \pm 8.83 \text{ kg/m}^2$, and $26.88 \pm 5.07 \text{ kg/m}^2$, respectively. Figure 1 shows overall sleep duration as reported by SenseWear Mini for

all days. Similar graphs for week day and weekend are shown in Figures 2 and 3, respectively. Figure 2 shows that pregnant women at week 18 of gestation and pregnant women at week 35 of gestation slept more on weekdays. Pregnant women at week 18 of gestation slept more than young adults and premenopausal women ($p = 0.017$ and 0.04 , respectively). Pregnant women at week 35 of gestation slept more than young adults with ($p = 0.04$). This relationship was not observed when looking at sleep duration for all days (Figure 1) and weekends (Figure 3). Sleep efficiency in percent was highest in the premenopausal women 86.53 ± 4.84 and lowest in the pediatric group 75.64 ± 7.44 . No significant differences in sleep efficiency were seen in the different groups of females. Application of the napping criteria to Excel data from SenseWear showed that most females did not nap on most days.

Discussion

This study was designed to measure the amounts of sleep in females across different life stages using an objective pattern-recognition system (SenseWear Mini). We hypothesized that pregnant women would have lower sleeping duration than women at all other life stages due to the physical discomforts associated with pregnancy. We also expected that sleep duration would be higher in children compared to adult females. The results show that pregnant women at weeks 18 and 35 of gestation actually got more sleep than young adult women and premenopausal women. Premenopausal women received the least amount of overall sleep which was 6.62 ± 0.687 hours. The National Sleep Foundation (NSF) recommends that adults should get 7 to 9 hours of sleep¹⁷. The overall sleep amounts received by the pediatric and young adult group was 6.86 ± 0.684

hours and 6.71 ± 0.988 hours, respectively which is lower than the 10 to 11 hours and 8.5 to 9.25 hours recommended for children and teens by the NSF¹⁷. According to the SenseWear Mini pattern-recognition monitor, women in all age categories slept less than the amounts recommended by the NSF.

Karacan et al. (ref. 18) found that pregnant women took significantly longer to fall asleep compared to a control group, 21.9 minutes vs. 10.9 min. Mean sleep durations were between 7.5 to 8.5 hours and total sleep time increased roughly 0.5 to 1 hour per day when compared with pre-pregnancy levels. This amount of increase in sleep with pregnancy is similar to what we observed in our study. As the pregnancy progresses, sleep becomes more fragmented resulting decrease in total sleep time back to pre-pregnancy levels. To compensate for disrupted night-time sleep pregnant women tend to sleep later, especially on weekends, and nap more often¹¹. In the present study, pregnant women slept approximately 25 minutes longer than the non-pregnant women and girls. Sleep efficiency (total sleep time divided by lying down time) was not significantly different between the groups of females.

The main advantage of this study is that there are very few studies that look objectively into the sleep of pregnant women and our study allows us insight into female sleep amount over various life stages and specifically pregnancy. It is interesting that pregnant women had more weekday sleep compared to non-pregnant women but perhaps pregnant women spend more time in sedentary activities or laying down which SenseWear Mini captures as sleep. Future studies which are designed to discern sedentariness from sleep/resting may be necessary to better address this issue. As noted by other researchers, pregnant women may also be compensating for sleep difficulties by

napping more. The present study showed that most women did not nap on most days regardless of reproductive status. Limitations to the study include that only one sleep measure was used, there were few females in each category, and there may have been participant bias relative to the study the female participated in. For example, all of the studies included were focused on understanding physical activity level in the study participants and were not focused on sleep. The study is strengthened because all studies used the same type of objective monitor to capture sleep.

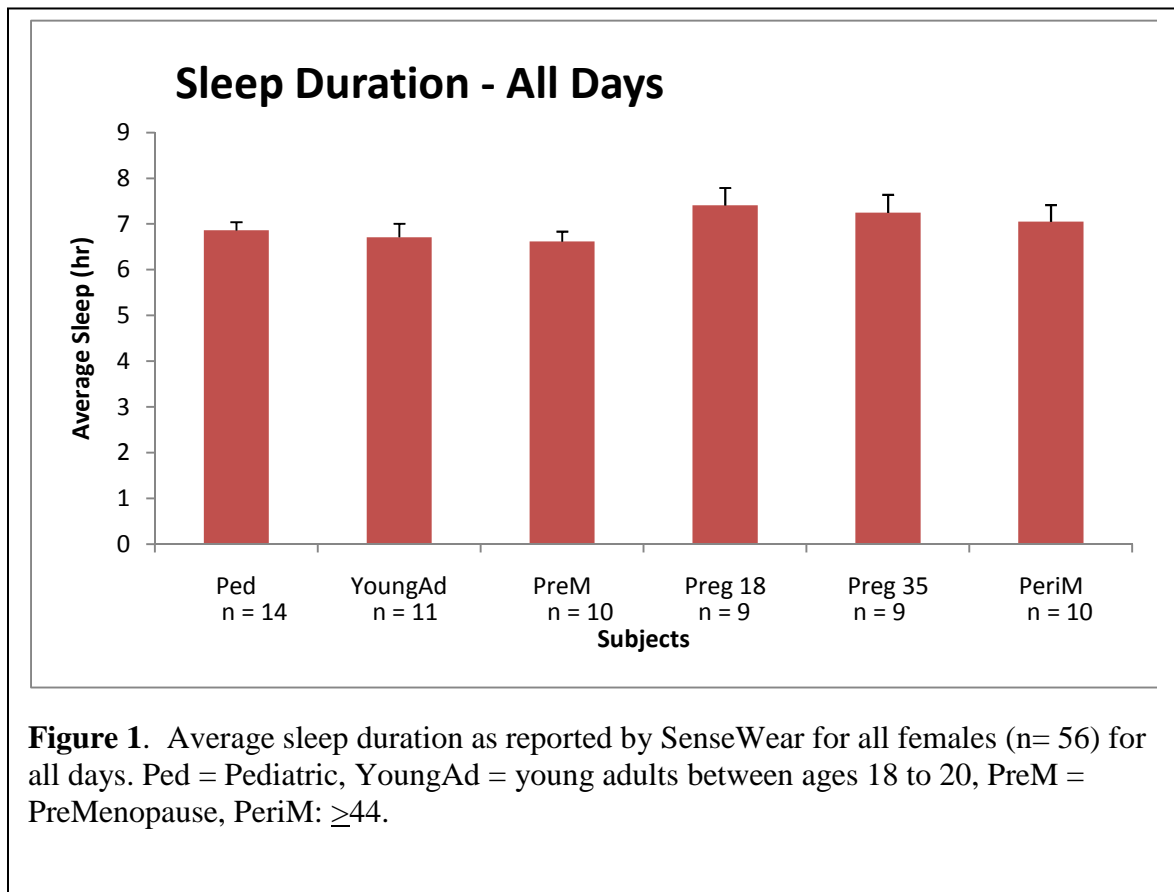
In conclusion, pregnant females slept more than non-pregnant females. Since the overall lack of sleep is evident, it would be interesting in a future study to explore if the suggestions by the National Sleep Foundation regarding sleep help to improve sleep. The NSF suggests strategies such as setting a sleep schedule, exposing oneself to bright light early in the morning and avoiding bright light at night, exercising regularly, establishing a relaxed bedtime routine, creating a cool and comfortable sleep environment, avoiding caffeinated beverages, tobacco, and chocolate at night, avoiding large meals and alcohol before bed time, and avoiding medications that disrupt sleep (NSF 2011). A future study across the life cycle in women should use methods to assess these sleep-related habits. Sleep questionnaires exist that would allow these key sleep habits to be assessed and sleep quality to be studied further. For future studies, it would also be beneficial to assess menstrual cycle phase in order to better group the females.

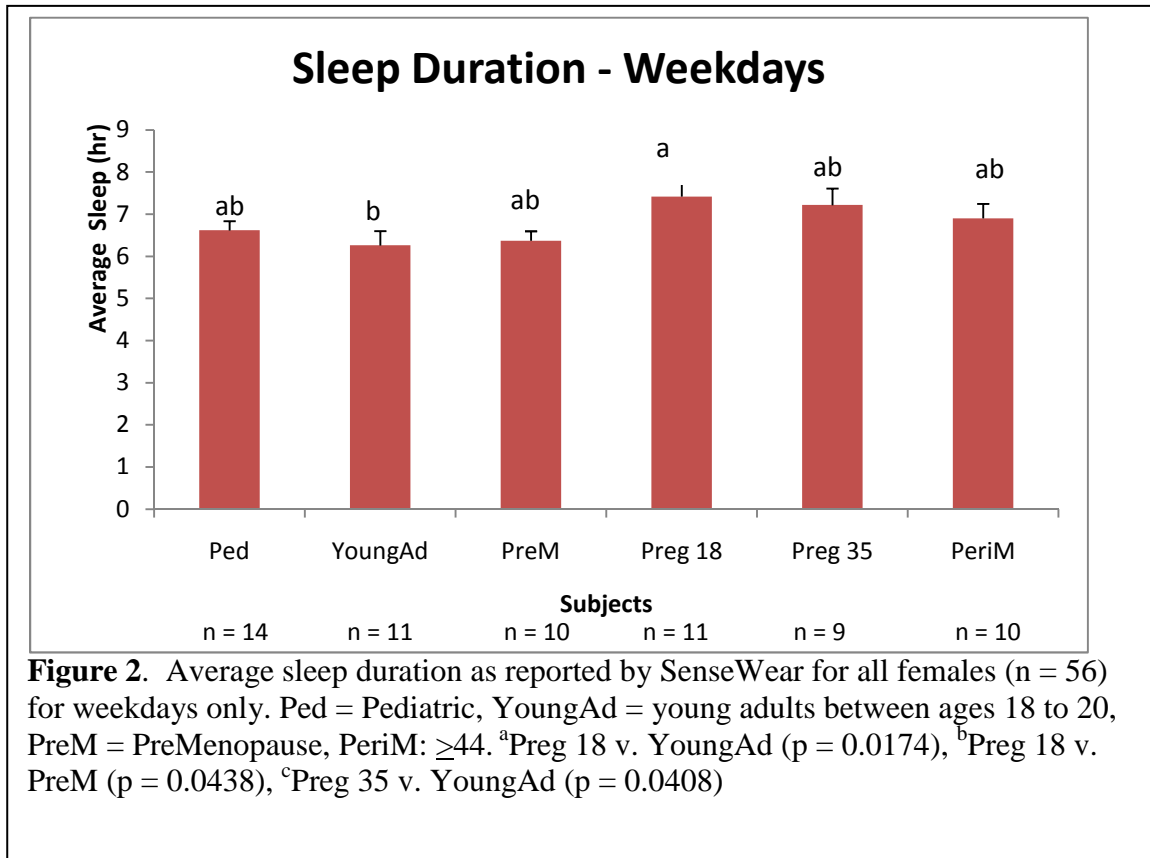
Tables and Figures

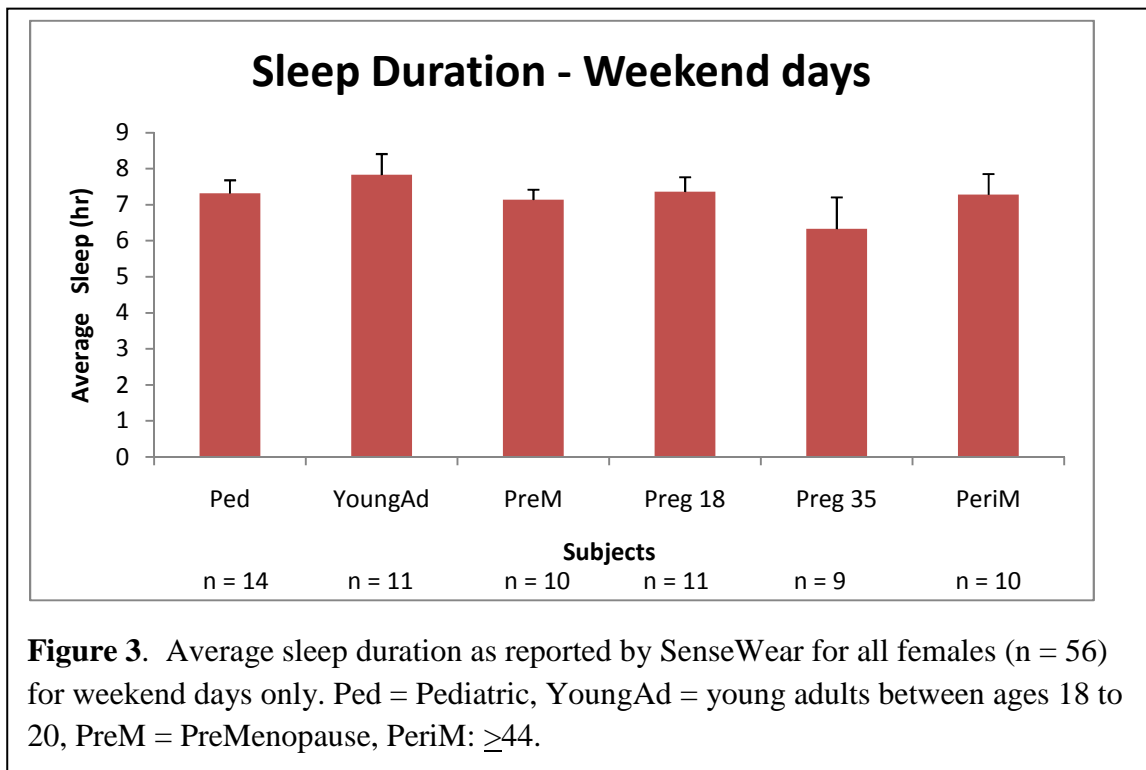
TABLE 1: Demographics for females participating in studies. Data shown are mean and standard deviation.

N = 56	Pediatric	YoungAd	PreM	Preg 18	Preg 35	PeriM
	(n=14)	(n=11)	(n=10)	(n=9)	(n=9)	(n=10)
Height (cm)	134.77 ± 33.62	154.64 ± 28.48	163.7 ± 7.89	164.27 ± 8.13	164.27 ± 8.13	164.8 ± 7.70
Weight (kg)	42.56 ± 25.86	88.18 ± 28.12	66.05 ± 12.25	69.45 ± 9.47	69.45 ± 9.47	74.07 ± 19.85
BMI (kg/m²)	17.24 ± 1.43	29.82 ± 3.56	24.87 ± 5.90	27.54 ± 6.07	27.54 ± 6.07	26.88 ± 5.07
BMI percentile	49 ± 19.35	--	--	--	--	--
Age (yrs)	11 ±1.9	19 ± 0.7	37 ± 4.4	29 ± 7.5	31 ± 2.0	49 ± 4.1
Sleep Efficiency (%)	76 ± 7.4	83 ± 6.8	87 ±4.8*	80 ± 10	79 ± 33	84 ± 4.0

Pediatric: <18 years of age. Young Adults: 18-20 year olds. PreM = Pre-Menopause, PeriM: > 43 years of age. *N= 8 due to missing data.







References

1. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The pittsburg sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Research*. 1989; **28**: 193-213.
2. Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. *Seminars in Neurology*. 2009; **29**: 320-39. Epub 2007 Apr 17.
3. Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR. Mortality associated with sleep duration and insomnia. *Archives of General Psychiatry*. 2002; **59**: 131-136.
4. Ferrie JE, Shipley MJ, Cappuccio FP, Brunner E, Miller MA, Kumari M, Marmot MG. A prospective study of change in sleep duration: associations with mortality in the whitehall II cohort. *Sleep*. 2007; **30**: 1659-1666.
5. Patel SR, Malhotra A, White DP, Gottlieb DJ, Hu FB. Association between reduced sleep and weight gain in women. *American Journal of Epidemiology*. 2006; **164**: 947-954.
6. Marshall NS, Glozier N, Grunstein RR. Is sleep duration related to obesity? A critical review of the epidemiological evidence. *Sleep Medicine Reviews*. 2008; **12**: 289-298.
7. Center for Disease Control and Prevention. About BMI for Adults. Available from http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html (cited 2011 March 3).
8. Chaput JP, Després JP, Bouchard C, Tremblay A. Short sleep duration is associated with reduced leptin levels and increased adiposity: results from the Québec Family Study. *Obesity*. 2007; **15**: 253-261.
9. Cournot M, Ruidavets JB, Marquie JC, Esquirol Y, Baracat B, Ferrieres J. Environmental factors associated with body mass index in a population of Southern France. *European Journal of Cardiovascular Prevention Rehabilitation*. 2004; **11**: 291-297.
10. Vorona RD, Winn MP, Babineau TW, Eng BP, Feldman HR, Ware JC. Overweight and obese patients in a primary care population report less sleep than patients with a normal body mass index. *Archives of Internal Medicine*. 2005; **165**: 25-30.
11. Moline ML, Broch L, Zak R. Sleep in women across the lifecycle from adulthood through menopause. *The Medical Clinics of North America*. 2004; **88**: 705-736.

12. Mindell JA, Jacobsen BJ. Sleep disturbances during pregnancy. *Journal of Obstetric, Gynecologic, and Neonatal Nursing*. 2000; **29**: 590-597.
13. Lee KA. Alterations in sleep during pregnancy and post-partum: a review of 30 years of research. *SleepMedicine Reviews*. 1998; **2**: 231-242
14. Medline Plus – Health Information from the National Library of Medicine. Menopause. Available from <http://www.nlm.nih.gov/medlineplus/menopause.html> (cited 2011 March 3).
15. National Sleep Foundation. NSF 2007 Sleep in America Poll Findings - PowerPoint Presentation. Available from <http://www.sleepfoundation.org/article/sleep-america-polls/2007-women-and-sleep> (cited 2011 March 7).
16. Sunseri M, Liden CB, Farrington J, Pelletier R, Safier S, Stivoric J, Teller A, Vishnubhatla S. The SenseWear armband as a sleep detection device. BodyMedia, Inc. 2005.
17. National Sleep Foundation. How much sleep do we really need? Available from <http://www.sleepfoundation.org/article/how-sleep-works/how-much-sleep-do-we-really-need> (cited 2011 March 7).
18. Karacan I, Heine W, Agnew HW, Williams RL, Webb WB, Ross JJ. Characteristics of sleep patterns during late pregnancy and the postpartum periods. *American Journal of Obstetrics and Gynecology*. 1968; **101**: 579-586.

CONCLUSIONS

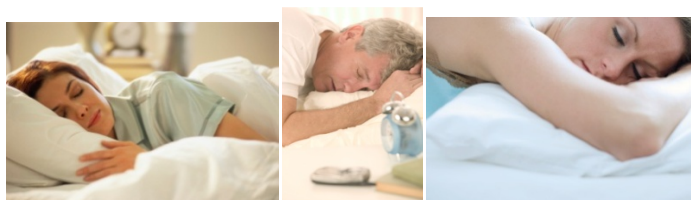
As part of my graduate studies at Iowa State University, I completed two studies to explore the relationship between sleep and obesity. The methods and results of these studies are described in detail in the chapters above. The purpose of the first study was to compare two new objective tools to subjective sleep logs in order to accurately determine sleep duration children and adults. The purpose of the second study was to examine sleep duration using an objective tool across the lifecycle of females and to compare sleep amounts in pregnant versus non-pregnant women.

The hypothesis of the first study was that objective and subjective tools would report similar sleep durations compared to a subjective sleep log. It was found that the objective tools and subjective tool captured fairly similar sleep duration from the children and adults. It was also seen that older individuals slept less compared to younger individuals. This is not a new observation, but helps to confirm that the tools used to capture sleep duration in the present study can indeed discern sleep duration between children and adults. Overall, this study was important because we may now use the objective tools (MSR and Sensewear) to better understand the relationships between sleep and other factors such as obesity and physical activity level. There are several existing studies in which these objective tools have been utilized and perhaps these earlier data sets from well-designed studies can be reexamined to understand sleep in various populations. The second study is a simple example of how this might be possible; sleep was examined in 4 studies which were originally designed to understand physical activity in 2 cross-sectional and 2 intervention studies with females.

For the second study, we hypothesized that pregnant females would have shorter sleep duration, especially at the later measurement period of 35 weeks gestation, compared to non-pregnant females due the added physical discomfort of pregnancy. It was found that pregnant women at week 18 of gestation slept more than young adults and premenopausal women. Pregnant women at week 35 of gestation slept more than young adults. This relationship was not observed when looking at sleep duration for all days and weekends.

Looking at the first study, there seems to be a strong association between sleep and age. Though sleep is not yet a modifiable risk factor for obesity, it is still essential to get an adequate amount of sleep. Based on the results, it was seen that the objective and subjective tools were fairly similar. For future studies, sleep logs could be used in conjunction with these objective tools as a low cost way to acquire sleep information while also capturing other factors that may influence sleep such as sleep environment, caffeine, alcohol effects, etc. What may also be very interesting is to explore existing data sets that have used the objective tools in order to gain more knowledge about the relationship between sleep, obesity, and physical activity. Focusing on the second study, females in all categories were not getting adequate amounts of sleep as recommended by the National Sleep Foundation (2011), thus suggesting that from a public health perspective, we need to encourage women to get more sleep. Until we have a better understanding of the relationship between sleep and obesity, perhaps a greater emphasis needs to be placed on public health messaging to encourage adequate sleep for all individuals.

APPENDIX A: Sleep and Body Weight Study Recruitment and Contact Materials



Individuals & Families Wanted!

Sleep and Body Weight study:

Opportunity to know more about your sleep!

Individual adults or children 7 and older and their families are needed for a research study being conducted to help understand possible relationships between sleep and body weight. The study will take place over one week. This study will require wearing small devices for a week. Payment will be offered for participation in the study. Your participation in this study is voluntary and your information will be treated with confidentiality if you choose to participate. Please contact Dr. Lorraine Lanningham-Foster (515-294-4684) or Randal Foster (515-294-0861) or e-mail to SleepISU@gmail.com for further information.

<p>Sleep and Obesity</p> <p>Lorraine Lanningham-Foster</p> <p>515-294-4684</p> <p>Randal Foster</p> <p>515-294-0861</p>	<p>Sleep and Obesity</p> <p>Lorraine Lanningham-Foster</p> <p>515-294-4684</p> <p>Randal Foster</p> <p>515-294-0861</p>	<p>Sleep and Obesity</p> <p>Lorraine Lanningham-Foster</p> <p>515-294-4684</p> <p>Randal Foster</p> <p>515-294-0861</p>	<p>Sleep and Obesity</p> <p>Lorraine Lanningham-Foster</p> <p>515-294-4684</p> <p>Randal Foster</p> <p>515-294-0861</p>	<p>Sleep and Obesity</p> <p>Lorraine Lanningham-Foster</p> <p>515-294-4684</p> <p>Randal Foster</p> <p>515-294-0861</p>
---	---	---	---	---

APPENDIX B: SLEEP AND BODY WEIGHT CONSENT/ASSENT FORMS

CONSENT FORM FOR: SLEEP AND BODY WEIGHT

This form describes a research project. It has information to help you decide whether or not you wish to participate. Research studies include only people who choose to take part—your participation is completely voluntary. Please discuss any questions you have about the study or about this form with the project staff before deciding to participate.

Who is conducting this study?

This study is being conducted by: Lorraine Lanningham-Foster, Randal Foster, Erin Thole, Kai Ling Kong, Shiny Parsai, Megan Barnes, Samantha Kling, Elsa Kracke and Maren Vik

Why am I invited to participate in this study?

You are being asked to take part in this study to understand if there is a relationship between an individual's sleep and body weight.

What is the purpose of this study?

The purpose of this study is to understand if there is a relationship between sleep and body weight. The project seeks to study which motion sensor (MSR or Sensewear) provides the most accurate sleep data in subjects when compared with a sleep log. The study also looks to understand late night snacking in individuals.

What will I be asked to do?

Before you start the study, you will be asked to come to the Nutrition and Wellness Research Center for a screening visit and to sign the consent form. We will measure your height and weight. We will ask you questions about your health and sleep.

You will then be asked to come to the Forker Building at Iowa State University. You will have your height and weight measured in a room so that it will be private and no one can see your height and weight. After having your height and weight measured, your body volume will also be measured. This measurement allows us to see how much fat is in your body. You will not be able to eat, drink, or exercise at least 2 hours before this test. You will bring along a pair of close-fitting underclothes or swim wear for this test. You will be in a private room for this test. After changing into the close-fitting clothing, we will also ask you to wear a swimcap. You will sit inside a chamber for approximately 5 minutes. This chamber is round and has a door that will close during the measurement. There is a window on the chamber so that you can see out.

The research study will last seven days. You will wear three motion sensors, one on each thigh and one on the arm. You will wear the motion sensors all day and night and take them off only to take a shower or bathe. You will come to the research center each day to get a clean pair of shorts and so that we can check the motion sensors. You cannot go swimming while wearing the motion sensors. You may also be recorded in your home while sleeping using a video camera. If your sleep is recorded during the study, on the first study day a study team member will come to your home and install a small video camera (webcam) in the room where you sleep. The video camera will be turned on and recording for the whole week of the study. If you are uncomfortable with this, please let the study staff know. You will be asked not to move the video camera during the recording days. Finally you will keep a daily sleep log, which will include some information about snacks, beverages, and medications. On the last day of the study, you will return all materials (motion sensors and sleep logs) to the NWRC. If you are a child and participating in this study, your parent(s) will complete a sleep questionnaire about your sleep habits over the last week on the last day of the study. If your sleep is recorded during the study week, a study team member will return to your home to collect the video camera and other study materials.

The following timeline may help you to understand all of the different meetings and measurements for this study:

Timeline

- Nutrition Wellness Research Center Building Screening Visit
 - First meeting with for consent/ assent form
 - After consent/assent: height and weight measured using weight scales and stadiometers
 - Body Mass Index (BMI) calculated
 - Next visit scheduled for body fat percentage measurement at Forker
- At Forker Building
 - Height and weight measured
 - Body fat percentage measured using BodPod
 - Schedule week of physical activity and sleep monitoring
 - Participants randomized (card in sealed envelope) to two groups: time-lapse webcam monitoring of sleep or no monitoring of sleep
 - If in the webcam group – schedule appointment to install the webcam in the participant's home at the beginning of the week-long measurement period

- Week of study
 - Meet with study staff to ensure that participants have shorts, sensors, and sleep log

What are the possible risks and benefits of my participation?

The risks of this research study are minimal. It might take a couple days to get used to the shorts and sensors. Pillows will be provided to help during sleep. In particular, you may experience some discomfort from the SenseWear Armband. You can move the sensor around occasionally to allow your skin to breathe. Some people experience a rash from wearing the armband. If you do get a rash we will allow you to remove the armband for one day. If you continue to have discomfort on your arm, you may want to stop your participation in the study.

If you are in the group which will have your sleep monitored by video camera, you may experience discomfort with having your sleep “recorded”. This data will be treated confidentially and after review and comparison of the recorded video camera sleep data to the sleep log and physical activity monitors, the video camera data will be destroyed.

If you decide to participate in this study there may be some slight benefit to you as you learn information about your body weight, body mass index, and body composition as it relates to health. It is hoped that the information gained in this study will benefit society by allowing us to explore electronic devices that will help use to learn more about sleep and body weight.

How will the information I provide be used?

The information you provide will be used for the following purposes: to study a possible relationship between sleep and body weight.

What measures will be taken to ensure the confidentiality of the data or to protect my privacy?

Confidentiality of all records is strictly maintained by established procedures. The original study data are kept in the study facility and are entered into a computer by the researcher. Physical records are stored under lock and key and electronic records through security passwords. The primary investigator will review all data. Participants will be informed about the potential for data and email messages to be intercepted and read. Violations of confidentiality will be immediately reported to the IRB. Study records will not identify subjects by name but using a numeric code.

Will I incur any costs from participating or will I be compensated?

You will not have any costs from participating in the study. You will be compensated 50 dollars for participating in the study. If you complete part of the study, you will be

provided with partial compensation. For the body composition measurement, you will receive \$15. For each day of physical activity monitoring and keeping sleep logs, you will receive \$5 (total of \$35 for entire week).

What are my rights as a human research participant?

Participating in this study is completely voluntary. You may choose not to take part in the study or to stop participating at any time, for any reason, without penalty or negative consequences.

Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

Whom can I call if I have questions or problems?

You are encouraged to ask questions at any time during this study.

Principal Investigator:

Dr. Lorraine Lanningham-Foster

Phone: 515-294-4684

- Questions about the study tests and procedures
- Research-related injuries or emergencies
- Any research-related concerns or complaints

IRB Administrator

- Phone: 515-294-4566
 - Rights of a research subject
 - Use of protected health information
 - Any research-related concerns or complaints
-
- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, 1138 Pearson Hall, Iowa State University, Ames, Iowa 50011.

Consent and Authorization Provisions

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) _____

_____	_____
(Participant's Signature)	(Date)

_____	_____
(Printed name of Parent/Guardian or Legally Authorized Representative)	(Date)

_____	_____
(Signature of Parent/Guardian or Legally Authorized Representative)	(Date)

Assent Form to Take Part in a Research Study (Ages 7-12)

TITLE: Sleep and Body Weight

Investigators: Lorraine Lanningham-Foster, Randal Foster, Erin Thole, Kai LingKong, Shiny Parsai, Megan Barnes, Samantha Kling, Elsa Kracke, and Maren Vik

ASSENT FORM

You are being asked to be in a research study. There are 2 initial study visits at Iowa State University and then you will be doing most of the study at your home for 1 week.

You are being asked to take part in this research study because we want to understand more about sleep and body weight.

The main things that you have to do while in this research study include having your height and weight measured, having your body fat measured, wearing activity monitors, and keeping track of your sleep. You will need to wear the activity monitors (on a pair of special shorts and one on your upper arm) for a whole week.

This is a timeline of the study that you will participate in:

1. Nutrition Wellness Research Center Building Screening Visit
 - a. First meeting with study team to sign assent form
 - b. After signing assent: height and weight measured
 - c. You and your parents will be asked questions about your health and sleep
 - d. Next visit scheduled at Forker Building
2. At Forker Building
 - a. Height and weight measured
 - b. Body fat measured in BodPod
 - c. Schedule week of physical activity and sleep monitoring
 - d. If in the webcam group – schedule appointment to install the webcam in your home at the beginning of the week-long measurement period. If you are in the webcam group, the webcam will always be turned on in your room. If you are uncomfortable with this, please let the study team know.
3. Week of study
 - a. Meet with you to check on study supplies (shorts, sensors, and sleep log).

We will keep the study information private. The study information is kept in the study office and is put into a computer by the study team. The computer is locked with security pass words. Any written records are stored under lock and key. Study records will not identify you by name and we will give you a number.

If you do not want to be in this research project, you do not have to say yes or sign your name on this form.

No one will be mad at you if you say no.

Assent by Child

Date

(Printed name of parent/guardian)

To the professional:

If the child does not sign the form, but you believe the child has actively assented, please document on this form. State the specific behaviors (head shake yes, child said okay after you described the procedure, etc.).

Researcher

Date

Assent Form to Take Part in a Research Study (Ages 13-17)

TITLE: Sleep and Body Weight

Investigators: Lorraine Lanningham-Foster, Randal Foster, Erin Thole, Kai Ling Kong, Shiny Parsai, Megan Barnes, Samantha Kling, Elsa Kracke, and Maren Vik

ASSENT FORM

You are being asked to be in a research study.

You are being asked to take part in this research study because we want to understand more about sleep and body weight.

This is a timeline of the study that you will participate in:

1. Nutrition Wellness Research Center Building Screening Visit
 - a. First meeting with study team to sign assent form
 - b. After signing assent: height and weight measured
 - c. You and your parents will be asked questions about your health and sleep.
 - d. Next visit scheduled at Forker Building
2. At Forker Building
 - a. Height and weight measured
 - b. Body fat measured in BodPod
 - c. Schedule week of physical activity and sleep monitoring
 - d. If in the webcam group – schedule appointment to install the webcam in your home at the beginning of the week-long measurement period. If you are in the webcam group, the webcam will always be turned on in your room. If you are uncomfortable with this, please let the study team know.
3. Week of study
 - a. Meet with you to check on study supplies (shorts, sensors, and sleep log).

First, you will come to the Nutrition and Wellness Research Center to learn more about the study and sign this form. Your height and weight will be measured after you sign this form.

Next, you will come to the Forker Building at Iowa State University. You will have your height and weight measured a second time at the Forker Building in a private room. Next, your body volume will also be measured. You will not be able to eat, drink, or exercise at least 2 hours before this test. You will bring along a pair of close-fitting underclothes or swim wear for this test. You will be in a private room for this test. After changing into the close-fitting clothing, we will also ask you to wear a swim cap. You will sit inside a chamber for about 5 minutes. This chamber is round and has a door that will close during the test. You will not be allowed to talk, sing, or laugh while in the chamber. There is a window on the chamber so that you can see

out. If you like, your parent(s) can stay with you for the whole test. Some people say that the test feels like you are riding on an elevator, if anything.

The research study will last seven days. You will wear three movement sensors, one on each thigh and one on your upper arm. The sensors that you wear on your thighs will be attached to a pair of shorts that you will wear under your clothes. You will wear the sensors all day and night. You can take the sensors off only to take a shower or bath. You will come to the research center each day to get a clean pair of shorts and so that we can check the sensors. You cannot go swimming while wearing the sensors. You may also be recorded while sleeping using a video camera. Finally you and your parent will write down how much time you sleep and answer questions about your sleep. At the end of the study, your parent(s) will fill out a questionnaire about your sleep.

We will keep the study information private. The study information is kept in the study office and is put into a computer by the study team. The computer is locked with security pass words. Any written records are stored under lock and key. Study records will not identify you by name and we will give you a number.

If you do not want to be in this research project, you do not have to say yes or sign your name on this form.

No one will be mad at you if you say no.

Assent by Child

Date

(Printed name of parent/guardian)

To the professional:

If the child does not sign the form, but you believe the child has actively assented, please document on this form. State the specific behaviors (head shake yes, child said okay after you described the procedure, etc.).

Researcher

Date

APPENDIX C: SLEEP AND BODY WEIGHT SLEEP LOG

NAME:

DATE From **To**

SLEEP LOG	Mon	Tues	Wed	Thurs
The quality of your sleep last night. Time you went to bed last night:				
Time you started your day today:				
On a scale of 1 to 10 (10=poorly), how well did you sleep?				
How long did it take to fall asleep?				
Total amount of time you slept:				
Describe the quality of your sleep that night. (Frequent waking? Deep sleep?)				
If you woke up during the night, how often? About what time(s)?				
Describe what woke you each time. (For example: worry, physical discomfort, sweating, need to go ot bathroom, etc.)				
Were you able to fall back to sleep?				
If not, about how long did you remain awake?				
Were you snoring, kicking, or tossing and turning during your sleep? (Ask your bed partner)				
Did you feel your breathing stop or a choking sensation?				
The day after... On a scale of 1 to 10 (10 = poorly), how well could you pursue the day's activities?				
Briefly describe your energy level, sleepiness, and ability to get work done.				
Did you need to take a nap? If yes, what time?				
Did you ... Experience any difficulties/stress during the day?				
Eat close to bedtime? If so, at what time? Fairly heavy meal? Just a snack?				
Drink beverages containing alcohol or caffeine? If yes, at what time? How many cups or glasses?				
Take any medications or drugs that evening? If yes, which ones? If yes, at what time?				

Child Sleep Questionnaire

Please mark only one most appropriate answer referring to your child's habitual sleep for the last four week.

Name of Parent: _____ Date: _____

Role of Responder: ☐ Father ☐ Mother

A. Sleep arrangement:

- ☐ Child's own bed (or equivalent sleeping surface) in separate room
- ☐ Child's own bed (or equivalent sleeping surface) in parents' room
- ☐ In parents' bed (or equivalent sleeping surface)
- ☐ Other (please specify):

B. In what position does your child sleep most of the time?

- ☐ On his/her belly ☐ On his/her side ☐ On his/her back

C. How much time does your child spend in sleep during the night?

() hr () min

D. What time does your child get into bed?

() hr () min

E. What time does your child fall asleep actually?

() hr () min

F. What time does your child wake up in the morning?

() hr () min

G. Is the bath time of your child fixed or flexible? ☐ Yes () hr () min ☐ No

H. How many night wakings (longer than 5 minutes) are usually noticed per night with your child? ()

I. How much time during the night does your child spend in wakefulness?

() hr () min

J. Is your child's sleep pattern stable? ☐ Yes ☐ No

K. (Only for parents who answered No to Question J)

Who is the most responsible for child's unstable sleep patterns? :

- ☐ Child him/herself ☐ Parents ☐ Unknown

L. Do you consider your child's sleep as a problem?

- ☐ A very serious problem ☐ A small problem ☐ Not a problem at all

REFERENCES

Acebo C, LeBourgeois MK. Actigraphy. *Respiratory Care Clinics of North America*. 2006 Mar; 12(1):23-30, viii.

Agras WS, Hammer LD, McNicholas F, Kraemer HC. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *Journal of Pediatrics*. 2004 Jul; 145(1):20–5.

Ahima RS, Antwi DA. Brain regulation and satiety. *Endocrinology Metabolism Clinics of North America*. 2008 Dec; 37(4):811–823.

Amagai Y, Ishikawa S, Gotoh T, Doi Y, Kayaba K, Nakamura Y and Kajii E. Sleep duration and mortality in Japan: the Jichi Medical School Cohort Study. *Journal of Epidemiology*. 2004 Jul; 14(4):124–128.

American College of Sports Medicine. ACSM. ACSM, AHA Support Federal Physical Activity Guidelines [Internet]. Indianapolis, IN: American College of Sports Medicine; c2007 [cited 2011 March 7].

Available from:

http://www.acsm.org/AM/Template.cfm?Section=Home_Page&TEMPLATE=/CM/HTMLDisplay.cfm&CONTENTID=11398.

Atkinson G, Davenne D. Relationships between sleep, physical activity and human health. *Physiology and Behavior*. 2007 Feb 28; 90(2-3):229–235. Epub 2006 Oct 25.

Behavioral Risk Factor Surveillance System. Prevalence and Trends Data: Overweight and Obesity (BMI) – 2009 [Internet]. Atlanta, GA: Center for Disease Control and Prevention; c2009 [cited June 15, 2011]. Available from:

<http://apps.nccd.cdc.gov/brfss/list.asp?cat=OB&yr=2009&qkey=4409&state=All>.

Benefice E, Garnier D, Ndiaye G. Nutritional status, growth and sleep habits among Senegalese adolescent girls. *European Journal of Clinical Nutrition*. 2004 Feb; 58(2):292–301.

Bjorkelund C, Bondyr-Carlsson D, Lapidus L, Lissner L, Manson J, Skoog I, Bengtsson C. Sleep disturbances in midlife unrelated to 32-year diabetes incidence: the prospective population study of women in Gothenburg. *Diabetes Care*. 2005 Nov; 28(11):2739–2744.

Bjorvatn B, Sagen IM, Oyane N, Wage S, Fetveit A, Palesen S, Ursin R. The association between sleep duration, body mass index and metabolic measures in the Hordaland health study. *Journal of Sleep Research*. 2007 Mar; 16(1):66–76.

Bloch KE. Polysomnography: a systematic review. *Technology and Health Care*. 1997 Oct; 5(4):285-305.

Brožek J, Grande F, Anderson JT, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. *Annals of New York Academy of Sciences*. 1963 Sep 26; 110:113-40.

Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The pittsburg sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Research*. 1989 May; 28(2):193-213.

Caballero B. The global epidemic of obesity: an overview. *Epidemiological Reviews*. 2007; 29:1-5. Epub 2007 Jun 13.

Cappuccio FP, D'elia L, Strazzullo P, Miller MA. Quantity and quality of sleep and incidence of type 2 diabetes: a systematic review and meta-analysis. *Diabetes Care*. 2010 Feb; 33(2):414–20. Epub 2009 Nov 12.

Carksdon MA, Dement WC. Normal human sleep: an overview in principles and practice of sleep medicine. 2nd ed. Philadelphia: Saunders Co; 1994. pp 16-25.

Carter PJ, Taylor BJ, Williams SM, Taylor RW. Longitudinal analysis of sleep in relation to BMI and body fat in children: the FLAME study. *British Medical Association*. 2011 May 26; 342:d2712.

Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports*. 1985 Mar-Apr; 100(2):126-31.

Caspersen CJ. Physical activity epidemiology: concepts, methods, and applications to exercise science. *Exercise and Sport Sciences Reviews*. 1989; 17:423-73.

Center for Disease Control and Prevention. Health Consequences [Internet]. Atlanta, GA: Center for Disease Control and Prevention; c2011a [cited 2011 March 3]. Available from: <http://www.cdc.gov/obesity/causes/health.html>.

Center for Disease Control and Prevention. About BMI for Adults [Internet]. Atlanta, GA: Center for Disease Control and Prevention; c2011b [cited 2011 March 3]. Available from: http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html.

Chaput JP, Brunet M, Tremblay A. Relationship between short sleeping hours and childhood overweight/obesity: results from the 'Quebec en Forme' Project. *International Journal of Obesity*. 2006 Jul; 30(7):1080–5. Epub 2006 Mar 14.

Chaput JP, Després JP, Bouchard C, Tremblay A. Short sleep duration is associated with reduced leptin levels and increased adiposity: results from the Québec Family Study. *Obesity*. 2007 Jan; 15(1):253–61.

Chen MY, Wang EK, Jeng YJ. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. *BioMed Central Public Health*. 2006 Mar 8; 6:59.

Cournot M, Ruidavets JB, Marquie JC, Esquirol Y, Baracat B, Ferrieres J. Environmental factors associated with body mass index in a population of Southern France. *European Journal of Cardiovascular Prevention Rehabilitation*. 2004 Aug; 11(4):291–7.

Daniels F, Alberty RA. *Physical chemistry*. New York: John Wiley and Sons, Inc, 1967.

Dempsey JA, Veasey SC, Morgan BJ, O'Donnell CP. Pathophysiology of Sleep Apnea. *Physiological Reviews*. 2010 Jan; 90(1):47–112.

Dempster P, Aitkens S. A new air displacement method for the determination of human body composition. *Medicine and Science in Sports and Exercise*. 1995 Dec; 27(12):1692-7.

Després JP, Lamarche B. Effects of diet and physical activity on adiposity and body fat distribution: implications for the prevention of cardiovascular disease. *Nutrition Research Reviews*. 1993 Jan; 6(1):137-59.

Dewit O, Fuller NJ, Fewtrell MS, Elia M, Wells JC. Whole body air displacement plethysmography compared with hydrodensitometry for body composition analysis. *Archives of Disease in Childhood*. 2000 Feb; 82(2):159:64.

Dieu HT, Dibley MJ, Sibbritt D, Hanh TT. Prevalence of overweight and obesity in preschool children and associated socio-demographic factors in Ho Chi Minh City, Vietnam. *International Journal of Pediatric Obesity*. 2007; 2(1):40–50.

DuBois D, DuBois EF. A formula to estimate the approximate surface area if height and weight be known. *Archives of Internal Medicine*. 1916; 17:863–71.

Eisenmann JC, Ekkekakis P, Holmes M. Sleep duration and overweight among Australian children and adolescents. *Acta Paediatrica*. 2006 Aug; 95(8):956–63.

Ferrie JE, Shipley MJ, Cappuccio FP, Brunner E, Miller MA, Kumari M, Marmot MG. A prospective study of change in sleep duration: associations with mortality in the whitehall II cohort. *Sleep*. 2007 Dec; 30(12):1659-66.

Fields DA, Goran MI, McCrory MA. Body-composition assessment via air-displacement plethysmography in adults and children: a review. *The American Journal of Clinical Nutrition*. 2002 Mar; 75(3):453-67.

Fogelholm M, Kronholm E, Kukkonen-Harjula K, Partonen T, Partinen M, Härmä M. Sleep-related disturbances and physical inactivity are independently associated with obesity in adults. *International Journal of Obesity*. 2007 Nov; 31(11):1713–21. Epub 2007 Jun 19.

Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk

factor for obesity: analyses of the NHANES I. *Sleep*. 2005 Oct; 28(10):1289–1296.

Gaina A, Sekine M, Chen X, Hamanishi S, Kagamimori S. Validity of child sleep diary questionnaire among junior high school children. *Journal of Epidemiology*. 2004 Jan; 14(1):1-4.

Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. *Seminars in Neurology*. 2009 Sep; 29(4):320-39. Epub 2007 Apr 17.

Gortmaker SL, Dietz WH Jr, Cheung LW. Inactivity, diet, and the fattening of America. *Journal of American Dietetic Association*. 1990 Sep; 90(9):1247–52,1255.

Gottlieb DJ, Redline S, Nieto FJ, Baldwin CM, Newman AB, Resnick HE, Punjabi NM. Association of usual sleep duration with hypertension: the Sleep Heart Health Study. *Sleep*. 2006 Aug; 29(8):1009–1014.

Gottlieb DJ, Punjabi NM, Newman AB, Resnick HE, Redline S, Baldwin CM, Nieto FJ. Association of sleep time with diabetes mellitus and impaired glucose tolerance. *Archives of Internal Medicine*. 2005 Apr 25; 165(8):863–7.

Gupta NK, Mueller WH, Chan W, Meininger JC. Is obesity associated with poor sleep quality in adolescents? *American Journal of Human Biology*. 2002 Nov-Dec; 14(6):762–8.

G, Buysse DJ, Klaghofer R, Gamma A, Ajdacic V, Eich D, Rossler W, Angst J. The association between short sleep duration and obesity in young adults: a 13-year prospective study. *Sleep*. 2004 Jun 15; 27(4):661–6.

Habicht, J.-P., Yarbrough, C. & Martorell, R. (1979). Anthropometric field methods: criteria for selection. In: *Human Nutrition, Nutrition and Growth* (Jelliffe, D.G. & Jelliffe, E. F. P., eds.), vol. 2, pp. 365-387, Plenum Publ. Corp., New York.

Hasler G, Buysse DJ, Klaghofer R, Gamma A, Ajdacic V, Eich D, Rossler W, Angst J. The association between short sleep duration and obesity in young adults: a 13-year prospective study. *Sleep*. 2004 Jun 15; 27(4):661–666.

Heslop P, Smith GD, Metcalfe C, Macleod J, Hart C. Sleep duration and mortality: the effect of short or long sleep duration on cardiovascular and all-cause mortality in working men and women. *Sleep Medicine*. 2002 July; 3(4):305–14.

Iglowstein I, Jenni OG, Molinari L, Largo RH. Sleep duration from infancy to adolescence: reference values and generational trends. *Pediatrics*. 2003 Feb; 111(2):302-7.

Iwasaki M, Iemura A, Oyama T, Matsuishi T. A novel subjective sleep assessment tool for healthy elementary school children in Japan. *Journal of Epidemiology*. 2010; 20 Suppl 2:S476-81. Epub 2010 Feb 23.

Jacobi D, Perrin AE, Grosman N, Doré MF, Normand S, Oppert JM, Simon C. Physical activity-related energy expenditure with the RT3 and TriTrac accelerometers in overweight adults. *Obesity*. 2007 Apr;15(4):950-6.

Jafari B, Mohsenin V. Polysomnography. *Clinics in Chest Medicine*. 2010 Jun;31(2):287-97.

Knutson KL. Sex differences in the association between sleep and body mass index in adolescents. *The Journal of Pediatrics*. 2005 Dec;147(6):830-4.

Knutson KL, Spiegel K, Penev P, Cauter EV. The metabolic consequences of sleep deprivation. *Sleep Medicine Reviews*. 2007a Jun;11(3):163-78.

Knutson KL, Lauderdale DS. Sleep duration and overweight in adolescents: self-reported sleep hours versus time diaries. *Pediatrics*. 2007b;119:e1056-62.

Ko GT, Chan JC, Chan AW, Wong PT, Hui SS, Tong SD, Ng SM, Chow F, Chan CL. Association between sleeping hours, working hours and obesity in Hong Kong Chinese: the 'better health for better Hong Kong' health promotion campaign. *International Journal of Obesity*. 2007 Feb;31(2):254-60. Epub 2006 May 23.

Kohatsu ND, Tsai R, Young T, Vangilder R, Burmeister LF, Stromquist AM, Merchant JA. Sleep duration and body mass index in a rural population. *Archives of Internal Medicine*. 2006 Sep 18;166(16):1701-5

Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR. Mortality associated with sleep duration and insomnia. *Archives of General Psychiatry*. 2002 Feb;59(2):131-6.

Krystal AD, Edinger JD. Measuring sleep quality. *Sleep Medicine*. 2008 Sep;9 Suppl 1:S10-7.

Lauderdale DS, Knutson KL, Yan LL, Rathouz PJ, Hulley SB, Sidney S, Liu K. Objectively measured sleep characteristics among early-middle-aged adults: the CARDIA study. *American Journal of Epidemiology*. 2006 Jul 1;164(1):5-16. Epub 2006 Jun 1.

Lauderdale DS, Knutson KL, Yan LL, Liu K, Rathouz PJ. Self-reported and measured sleep duration: how similar are they? *Epidemiology*. 2008 Nov;19(6):838-45.

Levine JA. Measurement of energy expenditure. *Public Health Nutrition*. 2005 Oct;8(7A):1123-32.

Lifson N, Gordon G, Vischer M, Nier A. The fate of utilized molecular oxygen and the source of the oxygen of respiratory carbon dioxide, studies with the aid of heavy oxygen. *Journal of Biological Chemistry*. 1949 Sep;180(2):803-11.

Locard E, Mamelle N, Billette A, Miginiac M, Munoz F, Rey S. Risk factors of obesity in a five year old population. Parental versus environmental factors. *International Journal of Obesity and Related Metabolic Disorders*. 1992 Oct;16(10):721-729.

Lohman, TG. Assessment of body composition in children. *Pediatric Exercise Science*. 1986;1:19-30.

Marshall NS, Glozier N, Grunstein RR. Is sleep duration related to obesity? A critical review of the epidemiological evidence. *Sleep Medicine Reviews*. 2008 Aug;12(4):289–98. Epub 2008 May 15.

McAllister EJ, Dhurandhar NV, Keith SW, Aronne LJ, Barger J, Baskin M, Benca RM, Biggio J, Boggiano MM, Eisenmann JC, Elobeid M, Fontane KR, Gluckman P, Hanlon EC, Katzmarzyk P, Pietrobelli A, Redden DT, Ruden DM, Wang C, Waterland RA, Wright SM, Allison DB. Ten putative contributors to the obesity epidemic. *Critical Reviews in Food Science and Nutrition*. 2009 Nov;49(10):868–913.

McCrory MA, Gomez TD, Bernauer EM, Mole PA. Evaluation of a new air displacement plethysmograph for measuring human body composition. *Medicine and Science in Sports and Exercise*. 1995 Dec;27(12):1686-91.

McCrory MA, Mole PA, Gomez TD, Dewey KG, Bernauer EM. Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes. *Journal of Applied Physiology*. 1998 Apr;84(4):1475-9.

Miwa H, Sasahara S, Matsui T. Roll-over detection and sleep quality measurement using a wearable sensor. Conference proceedings: Annual International Conference of the IEEE Engineering in Medicine and

Biology Society. IEEE Engineering in Medicine and Biology Society. Conference. 2007;2007:1507-10.

Miyatake N, Nonaka K, Fujii M. A new air displacement plethysmograph for the determination of Japanese body composition. *Diabetes, Obesity and Metabolism*. 1999 Nov;1(6):347-51.

Mokdad AH, Bowman BA, Ford ES, Vinicor F, Marks JS, Koplan JP. The continuing epidemics of obesity and diabetes in the United States. *The Journal of the American Medical Association*. 2001 Sep 12;286(10):1195-200.

Moreno CR, Louzada FM, Teixeira LR, Borges F, Lorenzi-Filho G. Short sleep is associated with obesity among truck drivers. *Chronobiology International*. 2006;23(6):1295–1303.

Mykityn IJ, Sajkov D, Neill AM, McEvoy RD. Portable computerized polysomnography in attended and unattended settings. *Chest*. 1999 Jan;115(1):114-22.

National Institutes of Health (NIH). Obesity Threatens to Cut U.S. Life Expectancy, New Analysis Suggests [Internet]. c2005 [cited 2011 June 15]. Available from: <http://www.nih.gov/news/pr/mar2005/nia-16.htm>.

National Sleep Foundation. 2005 adult sleep habits and styles, summary findings of the 2005 sleep in America poll [Internet]. Arlington, VA: National Sleep Foundation; c2011 [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/sleep-america-polls/2005-adult-sleep-habits-and-styles>.

National Sleep Foundation. 2009 Health and Safety Summary of Findings [Internet]. Arlington, VA: National Sleep Foundation; c2011 [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/sleep-america-polls/2009-health-and-safety>.

National Sleep Foundation. 2006 teens and sleep summary of findings [Internet]. Arlington, VA: National Sleep Foundation; c2011 [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/sleep-america-polls/2006-teens-and-sleep>.

National Sleep Foundation. Annual sleep in America poll exploring connections with communications technology use and sleep [Internet]. Arlington, VA: National Sleep Foundation; c2011 [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/press-release/annual-sleep-america-poll-exploring-connections-communications-technology-use->.

National Sleep Foundation. NSF 2007 Sleep in America Poll Findings - PowerPoint Presentation [Internet]. Arlington, VA: National Sleep Foundation; c2007 [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/sleep-america-polls/2007-women-and-sleep>.

National Sleep Foundation. How much sleep do we really need [Internet]? Arlington, VA: National Sleep Foundation; c2011. [cited 2011 March 7]. Available from: <http://www.sleepfoundation.org/article/how-sleep-works/how-much-sleep-do-we-really-need>.

Nixon GM, Thompson JM, Han DY, Bercroft DM, Clark PM, Robinson E, Waldie KE, Wild CJ, Black PN, Mitchell EA. Short sleep duration in middle-childhood: risk factors and consequences. *Sleep*. 2008 Jan;31(1):71–8.

Ogden CL, Carroll MD. Prevalence of Overweight, Obesity, and Extreme Obesity Among Adults: United States, Trends 1960–1962 Through 2007–2008 [Internet]. Center for Disease Control; 2010a Jun 4 [updated 2011 Jun 6; cited June 10]. Available from: http://www.cdc.gov/nchs/data/hestat/obesity_adult_07_08/obesity_adult_07_08.htm.

Ogden CL, Carroll MD. Prevalence of Obesity Among Children and Adolescents: United States, Trends 1963–1965 Through 2007–2008 [Internet]. Center for Disease Control; 2010b Jun 4 [updated 2010 Jun 4; cited June 10]. Available from: http://www.cdc.gov/nchs/data/hestat/obesity_child_07_08/obesity_child_07_08.pdf.

Ortiz O, Russell M, Daley TL, Baumgartner RN, Waki M, Lichtman S, Wang J, Pierson RN Jr, Heymsfield SB. Differences in skeletal muscle and bone mineral mass between black and white females and their relevance to estimates of body composition. *American Journal of Clinical Nutrition*. 1992 Jan;55(1):8-13

- Otto T, Lane D. Adipose development: from stem cell to adipocyte. *Critical Reviews in Biochemistry and Molecular Biology*. 2005 Jul-Aug;40(4):229-42.
- Ohayon MM. Interactions between sleep normative data and sociocultural characteristics in the elderly. *Journal of Psychosom Research*. 2004 May;56(5):479-486.
- Ohayon MM, Vecchierini MF. Normative sleep data, cognitive function and daily living activities in older adults in the community. *Sleep*. 2005 Aug 1;28(8):981-989.
- Okordudu DO, Jumeau MF, Montori VM, Romero-Corral A, Sommers VK, Erwin PJ, Lopez-Jimenez F. Diagnostic performance of body mass index to identify obesity as defined by body adiposity: a systematic review and meta-analysis. *International Journal of Obesity*. 2010 May;34(5):791-9. Epub 2010 Feb 2.
- Padez C, Mourao I, Moreira P, Rosado V. Prevalence and risk factors for overweight and obesity in Portuguese children. *Acta Paediatrica*. 2005 Nov;94(11):1550-7.
- Patel SR, Malhotra A, White DP, Gottlieb DJ, Hu FB. Association between reduced sleep and weight gain in women. *American Journal of Epidemiology*. 2006 Nov 15;164(10):947-54. Epub 2006 Aug 16.
- Patel SR and Hu FB. Short Sleep Duration and Weight Gain: A Systematic Review. *Obesity*. 2008 Mar;16(3):643-53. Epub 2008 Jan 17.
- Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity*. 2007 Oct;15(10):2371-9.
- Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *The International Journal of Behavioral Nutrition and Physical Activity*. 2008 Nov 6;5:56.
- Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I, Steer C, Sheriff A. Early life risk factors for obesity in childhood: cohort study. *British Medical Association (Clinical Research Edition)*. 2005 Jun 11;330(7504):1357. Epub 2005 May 20.
- Rothman, K.J. & Greenland, S. *Modern Epidemiology* 2nd ed. Philadelphia: Lippincott-Raven; 1998. 166-169 p.
- Schutte JE, Townsend EJ, Hugg J, Shoup RF, Malina RM, Blomqvist CG. Density of lean body mass is greater in blacks than whites. *Journal of Applied Physiology*. 1984 Jun;56(6):1647-9.
- Sekine M, Yamagami T, Handa K, Saito T, Nanri S, Kawaminami K, Tokui N, Yoshida K, Kagamimori S. A dose-response relationship between short sleeping hours and childhood obesity: results of the Toyama Birth Cohort Study. *Child: Care, Health and Development*. 2002 Mar;28(2):163-70.

Shigeta H, Shigeta M, Nakazawa A, Nakamura N, Yoshikawa T. Lifestyle, obesity, and insulin resistance. *Diabetes Care* 2001;24:608.

Singh M, Drake CL, Roehrs T, Hudgel DW, Roth T. The association between obesity and short sleep duration: a population-based study. *Journal of Clinical Sleep Medicine*. 2005 Oct 15;1(4):357–63.

Simon C, Gronfier C, Schlienger JL, Brandenberger G. Circadian and ultradian variations of leptin in normal man under continuous enteral nutrition: Relationship to sleep and body temperature. *The Journal of Clinical Endocrinology and Metabolism*. 1988 Jun;83(6):1893–9.

Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. *Nutrition*. 1993 Sep-Oct;9(5):480-91;discussion 480,492.

Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. *Lancet*. 1999 Oct 23; 354(9188):1435-9.

Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: Sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Annals of Internal Medicine*. 2004 Dec 7; 141(11):846–850.

Spruyt K, Gozal D. Development of pediatric sleep questionnaires as diagnostic or epidemiological tools: a brief review of dos and don'ts. *Sleep Medicine Reviews*. 2011 Feb;15(1):7-17. Epub 2010 Oct 16.

Snell EK, Adam EK, Duncan GJ. Sleep and the body mass index and overweight status of children and adolescents. *Child Development*. 2007 Jan-Feb;78(1):309–23.

Sunseri M, Liden CB, Farrington J, Pelletier R, Safier S, Stivorc J, Teller A, Vishnubhatla S. The SenseWear armband as a sleep detection device. *BodyMedia, Inc*. 2005.

Taheri S., Lin, L., Austin, D., Young, T. and Mignot, E. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. *PLoS Medicine*. 2004;1(3):e62. Epub 2004 Dec 7.

Taheri S. Sleep and metabolism: bringing pieces of the jigsaw together. *Sleep Medicine Reviews*. 2007 Jun;11(3):159–162.

Tamakoshi A, Ohno Y. Self reported sleep duration as a predictor of all cause mortality: results from the JACC study, Japan. *Sleep*. 2004 Feb 1;27(1):51–4.

Tasali E, Cauter EV. Sleep-disordered breathing and the current epidemic of obesity: consequence or contributing factor? *American Journal of Respiratory and Critical Care Medicine*. 2002 Mar 1;165(5):562–563.

Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise*. 2005 Nov;37(11 Suppl):S531-43.

US Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans [Internet]. Washington, D.C: US Department of Health and Human Services. [cited 2011 March 7]. Available from: <http://www.health.gov/Paguidelines/default.aspx>.

Vioque J, Torres A, Quiles J. Time spent watching television, sleep duration and obesity in adults living in Valencia, Spain. *International Journal of Obesity and Related Metabolic Disorders*. 2000 Dec;24(12):1683–1688.

Vorona RD, Winn MP, Babineau TW, Eng BP, Feldman HR, Ware JC. Overweight and obese patients in a primary care population report less sleep than patients with a normal body mass index. *Archives of Internal Medicine*. 2005 Jan 10;165(1):25–30.

von Kries R, Toschke AM, Wurmser H, Sauerwald T, Koletzko B. Reduced risk for overweight and obesity in 5- and 6-y-old children by duration of sleep—a cross-sectional study. *International Journal of Obesity and Related Metabolic Disorders*. 2002 May;26(5):710–716.

Wagner DR, Heyward VH. Validity of two-component models for estimating body fat of black men. *Journal of Applied Physiology*. 2001 Feb;90(2):649-56.

Weiss AR, Johnson NL, Berger NA, Redline S. Validity of activity-based devices to estimate sleep. *Journal of Clinical Sleep Medicine*. 2010 Aug 15;6(4):336-42.

Welk GJ, editor. *Physical Activity Assessments for Health-Related Research*. 1st edition. Champaign, IL: Human Kinetics; 2002.

Wells JCK, Douros I, Fuller NJ, Elia M, Dekker L. Assessment of body volume using three-dimensional photonic scanning. *Annals New York Academy of Sciences*. 2000 May;904:247–54.

Wolff B, Volzke H, Schwahn C, Robinson D, Kessler C, John U. Relation of self-reported sleep duration with carotid intima-media thickness in a general population sample. *Atherosclerosis*. 2008 Feb;196(2):727–32.

World Health Organization. 10 facts on Obesity [Internet]. WHO; c2011 [cited 2011 June 6]. Available from: <http://www.who.int/features/factfiles/obesity/facts/en/index.html>.

Wyatt SB, Winters KP, Dubbert PM. Overweight and obesity: prevalence, consequences, and causes of the growing public health problem. *The American Journal of Medical Sciences*. 2006 Apr;331(4):166-74.

Yi H, Shin K, Shin C. Development of the sleep quality scale. *Journal of Sleep Research*. 2006 Sep;15(3):309-16.

Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle-aged adults. *New England Journal of Medicine*. 1993 Apr 9;328(17):1230–5.

Zerfas AJ. Anthropometric field methods: general. In: Jelliffe DB, Jelliffe EFP, editors. *Human Nutrition: A Comprehensive Treatise*. 1979 Volume 2: Nutrition and Growth. Plenum Press, New York, p 339-364.

ACKNOWLEDGEMENTS

I would like to thank Dr. Lorraine Lanningham-Foster, my major professor, for encouraging me throughout my graduate program. Also, I would like to thank Randal Foster for his help with the statistics and data analysis. Thank you to Dr. Christina Campbell and Katie Smith for providing the data on pregnant females. Thanks to Megan Barnes and Samantha Kling for providing additional data on non-pregnant females. Thanks to Mary Wold for assisting with the study and the data entry. Thank you to all the participants of the study. Finally, thank you to my committee members and the Food Science and Human Nutrition faculty and staff for their encouragement and support throughout my graduate studies at Iowa State University.